CEREAL RUSTS

1916

THESIS

Presented to the Department of Field Husbandry University of Saskatchewan in Partial Fulfilment of the Requirements for the Degree of Bachelor of Science in Agriculture

by

Arthur W. Henry.

CEREAL RUSTS - 1916.

Introduction

The summer of 1916 will live in the memories of the people of Western Canada and the U.S.A. as one of the most severe ever experienced, from the standpoint of damage to cereal crops, wrought by rust.

Coming at such a critical period in the history of the world, this disaster has had a national importance that as yet, is probably underestimated. Its ravages have been widespread, especially in the spring wheat sections of North America, and its virulence enhanced by the favorable season, has demonstrated once more the dreaded possibilities of the disease, when the proper environment for its maximum development is provided by Nature.

Besides giving the farmer an ocular demonstration of the difficulties presented in combating such a pest, this epidemic has served to emphasize some outstanding features of the disease in relation to cultivated crops, which in turn have suggested and confirmed a few practical and feasible means of control. It is to be hoped that the improvements in grain production resulting from lessons learned at this time will counterbalance several times over the actual loss sustained in the deficiency of grain production this one season.

History of Rust

Rust is not something new, as some of us are led to believe by its periodical appearances. It seems to come from nowhere, yet it is ever present. If however the proper conditions for its development are lacking, the disease may be hardly noticeable.

Observations were made on the effect of weather and location on rust by the ancients. The comparative susceptibility of different cereals to rust is mentioned by Theophrastus, and Pliny says that barley is less likely to rust than other grains. Shakespeare in King Lear seems to have been acquainted with rust -"The foul fiend "Flibbertigibbet" mildews the white wheat" - "mildew" being the confusing term by which many English writers designate the Stem-rust of wheat, Puccinia Graminis.

Our modern high power microscope and other recent inventions have done much to increase our knowledge of rust and like diseases. There are, no doubt, still many forms and species of the disease which are entirely unknown, since new ones are frequently being added to the already long list. Our knowledge of the most common forms is still far from complete.

Distribution and Losses Occasioned

Rusts are universally distributed wherever wheat is grown. Any country which produces the cereals, wheat, oats, barley and rye suffers occasionally from outbreaks of rust. On account of destruction by this pest, warm moist countries like China and Japan are unable to successfully produce the wheat crop. Australian and Russian fields suffer more or less annually while in England where intensive systems of agriculture are imperative, the wheat crop is often reduced to one-half of inferior quality.

Since outbreaks occur so irregularly and are so greatly affected by weather conditions, statistics as to the actual losses occasioned are difficult to compile. Where frost or drought also appear in the same season, producing the same shrunken effect on the kernel, the difficulty of determining the damage done by the rust itself is considerably increased.

In 1891 Galloway judged the loss due to rust alone on the wheat crop in the U.S.A. at $67000000. and in the same year Prussia lost 31% of her wheat crop from the same cause. Various crop experts placed the loss to the wheat crops of the North West States for the season of 1905 at 30,000,000 bushels. Through South Dakota that same year the loss approximated 50% of the average annual crop. Prof. Bolley estimates the annual loss to the wheat crop of the U.S.A. at $20,000,000. Australia loses yearly two or three millions sterling from rust.

The year 1916 has been by far the worst rust year that North America has experienced since 1904. Western Canada has never suffered so much before from this cause. Of the three prairie provinces Manitoba was the greatest loser, Saskatchewan next and Alberta the smallest. Hail and frost were also prevalent and did much damage. For the former the wise farmer was protected by insurance and for the latter he is generally on the look-out and governs his

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The following figures show the wheat acreage, the total yield, and the average yield per acre in the three prairie provinces over a period of years. They may not correspond exactly with the estimates made by the provincial governments but they serve the writer's purpose in that they show the 1916 yield in the three provinces compared with former years and thus give the reader an idea of the relative losses occasioned, due to the combined effect of rust, frost, hail, etc.

Manitoba's Wheat Acreage and Yield
Since 1880.

Year	Acreage	Total Yield	Bushels per acre.
1880	51,293	1,033693	20.15
1890	896,622	16,092,220	17.94
1900	1,965,200	18,353,013	9.33
1905	2,417,253	47,626,586	19.7
1906	2,721,079	54,472,198	20.01
1908	2,957,000	50,269,000	17.00
1909	2,808,000	52,706,000	18,76
191o	2,759,444	34,127,598	12,35
1911	3,081,542	62,309,000	20.22
1912	2,824,000	62,684,000	22,20
1913	2,785,000	52,943,000	19.01
1914	2,601,000	38,365,000	14,75
1915	3,332,000	96,062,000	28.83
1916	2,333,000	24,497,000	10.50

According to these figures, Manitoba had the lowest yield per acre this year, since 1900. It is estimated that 17% of her wheat crop, 2½% of her oat crop, 3¾% of her barley crop sown in 1916 was a total loss. This amounted to 502,000 acres of wheat, 37,000 acres of oats and 19000 acres of barley. In addition to that totally lost 118,000 acres of wheat, and 70,000 acres of oats intended for grain was cut for green feed.

The figures for Saskatchewan are as follows:

Acreage and Yield since 1900

Yield	Acreage	Total Yield	Bushels per acre
1900	482,212	4,306,811	8.93
1905	1,376,281	31,799,198	23.10
1906	2,117,484	50,182,359	24.22
1908	2,396,000	34,742,000	14,44
1909	3,685,000	85,197,000	23,11
1910	4,226,992	66,964,653	15.84
1911	5,253,836	109,017,000	20.75
1912	5,579,000	106,895,000	19.16
1913	5,716,000	121,465,000	21.35
1914	5,344,000	73,427,000	13.74
1915	6,834,000	195,042,000	28.54
1916	5,248,000	83,958,000	16.00

Although suffering considerably Saskatchewan had a higher yield per acre than in the dry year of 1914 and a much better price. In Saskatchewan 9% of the wheat crop, 4% of the oat crop and 3½% of the barley crop was a total loss. This amounted to 532,000 acres of wheat, 117,000 acres of oats, 8,500 acres of barley -- being in this case largely hail losses. In addition 133,000 acres of wheat and 16,000 acres oats intended for grain were cut for feed.

Alberta Wheat Acreage and Yield
Since 1900

Year	Acreage	Yield	Bushels per acre.
1900	43,062	879,756	20.43
1905	147,835	3,035,843	20.53
1906	223,930	5,932,267	26.49
1908	271,000	6,842,000	25.24
1909	385,000	9,579,000	24.88
1910	674,665	6,736,680	9.98
1911	1,334,186	28,872,000	21.64
1912	1,378,000	29,675,000	21.54
1913	1,310,000	30,130,000	23.00
1914	1,150,000	24,150,000	21.00
1915	1,348,000	44,039,000	32.67
1916	1,226,000	29,118,000	23.75

This shows a very good average yield per acre for 1916. Nevertheless of Alberta's wheat crop 5¾% or 79,000 acres was a total loss this year, also 4% of her oat crop or 75,000 acres and 3¾% of barley crop or 6000 acres. In addition 61,000 acres of wheat and 15,000 acres of oats intended for grain were cut for feed.

Besides the above diminution in yield, due largely to the ravages of rust, the shrunken condition of the kernel has also caused large losses in grade, in dockage, and in the value of the grain for seed. To meet the particular conditions of this year three special grades were established at Winnipeg, namely No.4 Special (rusted), No.5 Special (rusted) and No. 6 Special (rusted) in addition to the regular No.4, No.5 and No.6 Northern. Had it not been for the high prices which prevailed during 1916 the farmer would have felt the effects of this disaster to a much greater extent than he has.

Cause of the Outbreak

Some contend that rust epidemics are due to a depletion of soil fertility and are becoming worse from year to year as the soils wear out. Others say that our crops have deteriorated and hence are more susceptible to rust than formerly. On the contrary it has been frequently observed that the newest land in a district often harbors the worst cases of rust and that instead of the weak plants in the field carrying the most rust it is generally the case that the most succulent, and well nourished plants are the worst attacked. The real reason for the unusual abundance of rust in 1916, as in 1904 was the exceptionally wet season.

The year 1915 was considered a wet year whereas during June, July and August of 1916 at Saskatoon, the rainfall was 50% higher, the humidity 4.1% higher and the average temperature several degrees higher than for the same months of 1915. The cloudy days and wet weather tended to prolong the period from the time the wheat started to blossom until the kernels were filled out. Since it is during this period that the rust does the most damage and since this period was prolonged and the proper conditions for the germination of the rust spores, i.e. a fairly high temperature, with conditions tending to keep the plants moist, such as heavy dews and muggy weather - were in the meanwhile supplied, it is not hard to see how the peculiarities of the season were so conducive to an outbreak of the disease. Such weather is also conducive to a luxuriant crop growth so that conditions most favorable for crop growth are also most advantageous for the growth and spread of the rust fungus.

We must not forget however that the weather alone cannot produce the disease. The seeds or spores of the rust as they are called must be present and viable and must be scattered from place to place by the wind. The combination of such conditions results in our periodical outbreaks of rust.

Nature of the Disease

Disease in a plant may be caused by any agency which produces a disturbance in its mechanism tending to hinder or arrest the activity of any part. Insufficient nourishment, excessive heat or cold, over abundance of plant food, lack of some particular constituent in the soil, the presence of some poisonous substance, or mechanical injury, may modify or retard proper development. Such natural phenomena are active in producing plant diseases, diseases which however are purely environmental and not transmissible from one plant to another.

Other types of disease such as that to which rust belongs, are due to living organisms and since they may be spread from plant to plant and from crop to crop are designated infectious diseases. In fact they may be carried to any part of the world and there they will grow, provided they find a suitable environment and have not been killed in passage.

Since then such diseases are due to living organisms we can see how their development can be so greatly affected by meteorlogical conditions, i.e., heat, light, moisture, etc. There is then justification for the common idea that rust outbreaks are due to the weather. "Just as iron rusts when left exposed in the damp air, so does the wheat plant become attacked." Such erroneous ideas are ridiculous to the scientific student and yet it is astonishing how prevalent natural inferences such as this are among those who have not had an opportunity of examining minutely into the reasons and causes of things.

When we come to consider that rust and like infectious diseases which prey upon plants, are themselves plants it is a fairly simple matter to understand their distribution, their habits of growth and the destruction done by them. They are termed parasites since they do not manufacture their own food but obtain it from other plants which contain chlorophyll (the green coloring matter possessed by all plants that manufacture their own food). The main part of the plant consists of a tangled mass of colorless threads called the mycelium, the separate branches of which are known as hyphae. This mycelium corresponds to the leaves, stems and roots of higher plants but possesses no such differentiation like the latter. It is the mycelium that penetrates the host plant, perforates its cells and absorbs the nourishment from it. It is for this reason that Rust does damage and is known as a disease. At intervals branches or hyphae seek the surface of the plant attacked and cut off from their ends minute bodies, sometimes red, sometimes black, brown, yellow, orange or colorless. These spores as they are called usually occur in groups forming the characteristic pustules so evident to the naked eye. They serve to spread or propagate the disease performing the same functions for the parasite as seeds do for higher plants.

Plants affected by Rust

Because cultivated crops are more closely under our observation we generally think of rust as being confined to such plants. In fact so much damage is done to cereals by rust, we are apt to infer that they alone are the only plants injured. The farmer as a rule looks upon a field of wheat as a crop, as a mass of plants, not as a collection of individual plants each possessing characteristics of its own. He therefore does not notice that some have long straw and some short, some white straw and some purple, some velvet chaff and some smooth chaff -- neither does he notice that some are attacked by rust more than others growing side by side. For the same reason his attention is not attracted by the fact that wild plants growing right beside his wheat field are also infected with rust. Such however is the case and quite frequently the same species of rust is the cause of both infections. Besides attacking wheat, oats, barley, rye, corn and flax, ~~this disease~~ rust is found on many native and other cultivated grasses, on the fruit trees of orchards, on the vegetables and even the ornamental plants of our gardens. There are one or more rust diseases for nearly every cultivated crop.

Classification of Rust in the Plant Kingdom

There are four great groups of plants. -- (1) the spermatophytes, or seed plants, (2) the pteridophytes or fern plants, (3) the bryophytes or moss plants and (4) the thallophytes, the lowly or prostrate plants, which group includes the fission plants, the fungi and the algae. The latter group contains the lowest forms of plant life known. These plants are characterized by the possession of a "thallus" - the body of the plant exhibiting no differentiation of leaf, stem and root. Of the thallophytes the subgroup fungi, i.e., thallophytes which do not possess chlorophyll, is of vast economic importance, since it contains plants which cause by far the greatest number of plant diseases. The fungi are divided further into (1) Phycomycetes (2) Ascomycetes (3) Lichens (4) Basidiomycetes. The most prominent members of the group Basidiomycetes are the smuts, the rusts, the toadstools, mushrooms, and puff-balls.

The Basidiomycetes are a great group of fungi characterized by the occurrence of a basidium in their life history. A basidium is a swollen end of a hypha, and consists of four cells or one cell, but in either case it usually gives rise to four slender branches (sterigmata) and each sterigmata usually cuts off at the tip a spore (basidiospore). The classification of this group is very uncertain. However two series may be recognized, (1) Protobasidiomycetes, in which the basidium is four celled, each cell bearing a spore and (2) Autobasidiomycetes.

Of the Protobasidiomycetes the two most important divisions are (a) Ustilaginales - the smuts or brand fungi (b) Uredinales - the well known rusts, all of which are destructive parasites, whose mycelia live in the intercellular spaces of higher plants, especially of the leaves. The best known form of this group is Puccinia Graminis (the Stem rust or Black rust of wheat), by far the most destructive form in our wheat fields this year.

Most species of Uredinales have more than one stage of growth, distinguished by the form and arrangement of the spores which they produce; the number of distinct kinds of spores which a single species can possess varies from one to five. If the various spore forms are all borne on one host the species is said to be autoecious , e.g. Rose Rust, Phragmidium; Asparagus rust, Puccinia Asparagi; Flax rust, Melampsora lini. It is a remarkable fact however that a large number of the Uredinales pass their existence alternately upon two hosts, certain of the spore forms being always produced upon the one, and the remainder upon the other. Such species are called heteroecious, e.g. most cereal rusts. So unlike are these stages that formerly they were named as distinctly different plants, and it is only recently that enough has been learned about them to enable us to know some of the different appearances which they may assume.

To give some idea of the immense number of forms of Uredinales - the genus Puccinia alone contains over 1300 identified species. Of these Puccinia graminis, being of such economic importance, and because its life history is better known than that of most forms, a detailed account is given in the following pages.

Life History of Puccinia Graminis.

The "Black Rust" or "Stem" Rust of wheat.

Distribution: -

In every country of the world.

The first conspicuous appearance of this rust in the early summer is in the form of reddish brown patches upon the stalks and leaves of wheat. These spots are long and narrow and are caused by multitudes of "summer spores" (uredospores), which are cut off from the tips of fungus threads and which break through the epidermis of the wheat plant. If a section is cut through the host plant and examined under the microscope it will be seen that these fungus threads or hyphae extend down between the cells of the host plant , branching and rebranching to form a net-work of threads (the mycelium). At the time the uredospores are formed the host plant is usually thoroughly infested with the mycelium. Here and there small branches (haustoria)from the mycelium, are sent into the cells of the wheat plant, thus robbing the latter of some of its nourishment. These uredospores are readily blown about by currents of air. If a spore alights on a wheat plant, it proceeds to germinate in the dew or film of moisture deposited on the plant, and grows down into the living tissues of the plant. After developing thus inside the wheat plant for ten days or so another crop of reddish spores is produced, which in turn may spread the disease to other plants, This continues all through the summer under favorable conditions so that one spore multiplies itself many thousand times. Since the uredospores are capable of reinfecting the wheat in this manner and since they spread the disease so effectively and so rapidly, this stage does the greatest amount of damage. Many farmers seem to have the idea that the Black Stage creates the greatest destruction but it will be seen as we proceed that this is not the case.

This stage of the disease is sometimes referred to as "Red Rust" but to save confusion it would be better to term it the "Red Stage"of the Black Rust or Stem Rust of wheat. Many other rusts have a red summer stage in their life history.

As regards the appearance of the uredospores under the Microscope. They are one-celled, longer compared with their breadth (more elipsoid), than is the case with other cereal species, and generally have four equatorial germ pores. See Fig. I.A.

Later in the summer the same mycelium which produced the uredospores may bear dark brown or black thick walled, two celled spores known as winter-spores or teleutospores, (Fig. I. C) Groups of these bursting through the surface of the wheat plant form the characteristic black pustules which give this rust its name. The thick wall which these spores possess is a provision of nature to enable them to stand adverse conditions. Unlike the uredospores they are incapable of infecting the wheat plant and must pass through a period of rest before they can be induced to germinate. For this reason they do not cause the damage that the uredospores do. They are important however in order to carry the rust over the winter.

STAGES in the LIFE HISTORY of PUCCINIA GRAMINIS

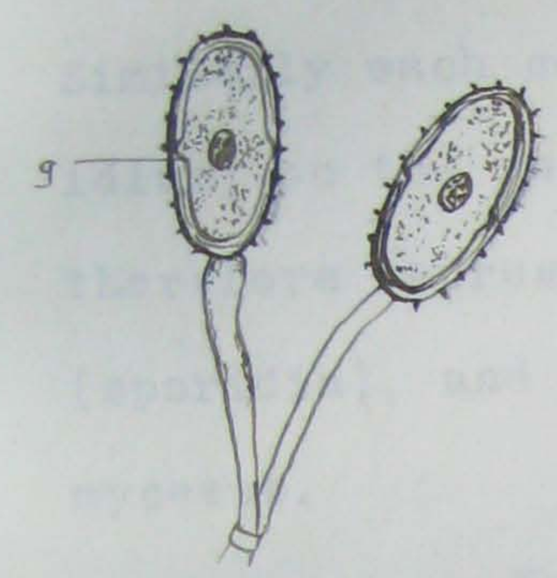


Fig. 1A

g = germ pore

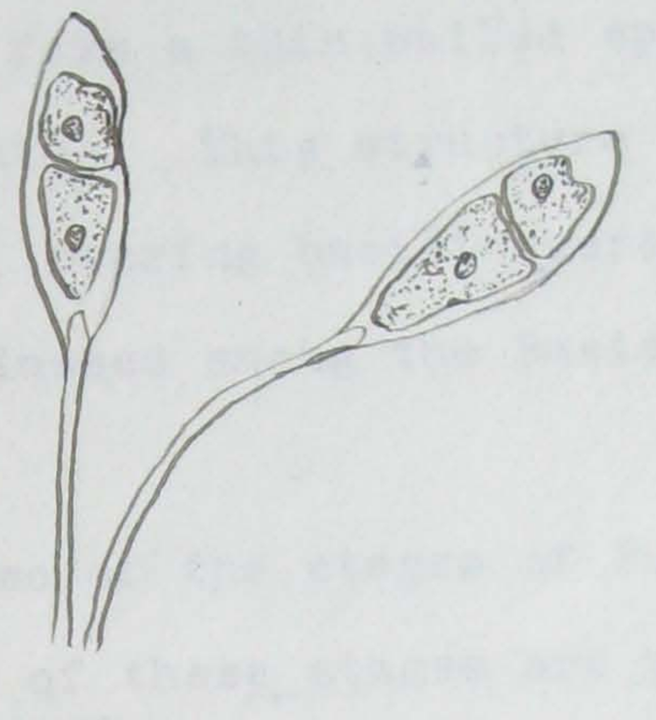


Fig. 1C.

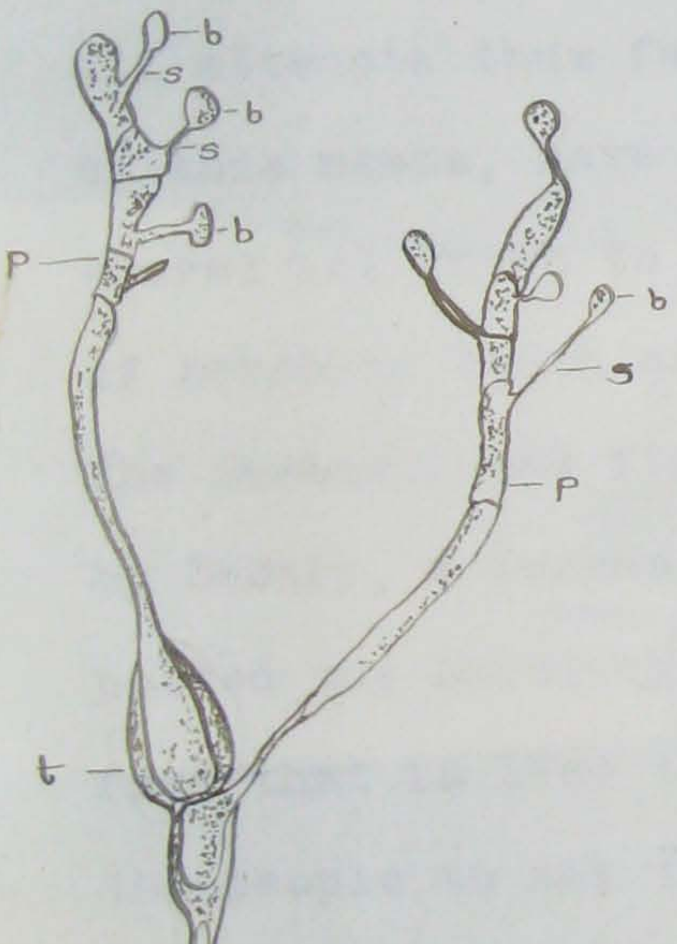


Fig. 1D

b - basidiospore or sporidium
s - sterigmata
p - promycelium
t - teleutospore

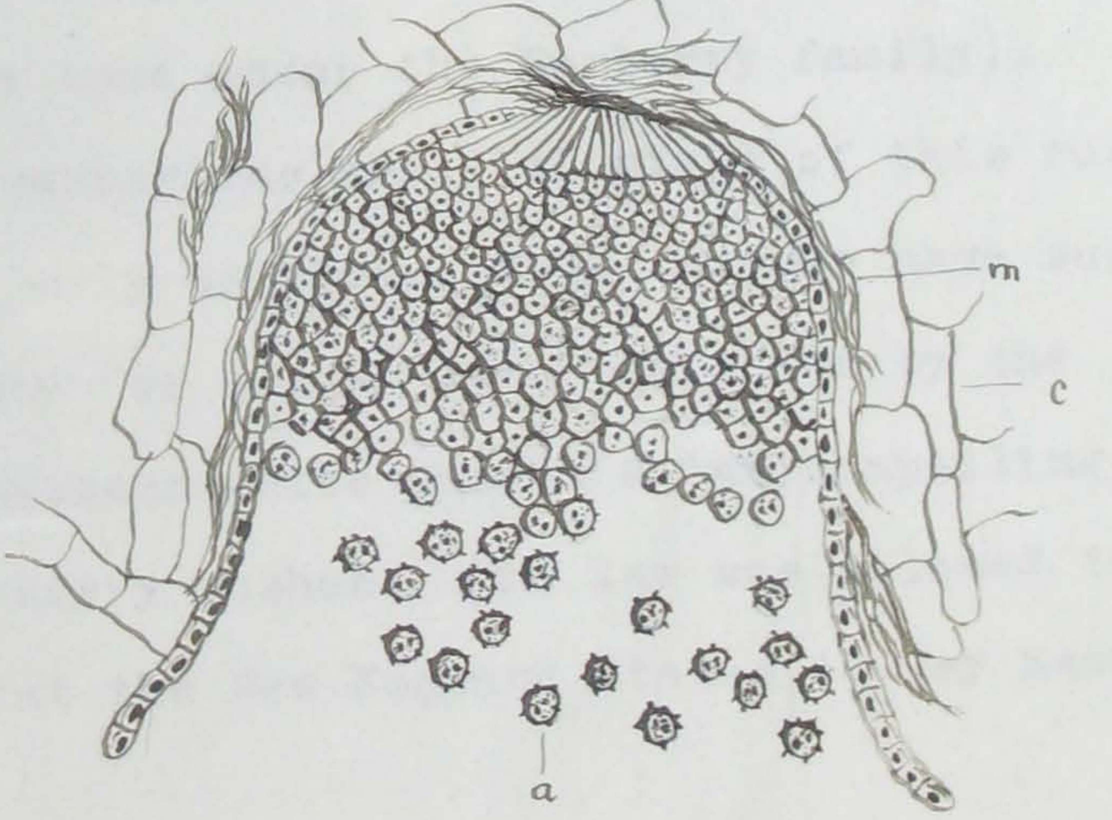


Fig. 1E

c = cells of Barberry Leaf
m = mycelium
a = aecidiospore

They remain in a dormant condition on the straw over winter, but when the warm spring days arrive they proceed to germinate in the moisture then present. From each cell of the teleutospore there grows a small hypha (promycelium), usually consisting of four cells (Fig.1.D.) Similarly each cell of this promycelium may form a thin walled spore (Sporidium) on the end of a short stalk (sterigmata). This structure therefore represents a four-celled basidium, bearing basidiospores (sporidia), and for this reason rusts are classed among the Basidiomycetes.

Thus far we have considered two of the stages of Puccinia Graminis, and it will be observed that both of these stages are produced on the wheat plant itself. The sporidia however which are produced upon the germination of the teleutospores, are incapable of infecting the wheat plant. Wheat plants in all stages have been inoculated with sporidia by various experimenters. Different parts of the plant such as root, seed, leaf and stem have been tried but all attempts thus far to introduce the disease into the wheat plant by this means, have proven unsuccessful. The only plants which these spores are known to attack are Mahonia Aquifolium and certain species of Berberis (both of which genera come under the Barberry family). The Barberry was first shown to harbor the aecidial stage of this rust by DeBary, a German Botanist as early as 1864. That farmers have suspected the Barberry as their enemy for a long time, is shown by the fact that in 1760 the state of Massachusetts passed a law compelling the people to cut down their barberry bushes. The law was allowed to lapse however with the result that the New England States to-day have Barberry bushes in abundance.

When the sporidia alight on the moist leaves or fruit of the Barberry they germinate and produce within the tissues of the leaf an extensive growth of mycelium. Sooner or later (15 to 20 days) the hyphae of this mycelium cut off spores which are borne in cup-shaped cavities on the under surface of the Barberry leaf (Fig. 1.E). The spores thus produced (aecidiospores) arise in chains from the bottom of the cup-shaped depressions. These cups are sufficiently large to be seen readily with the naked eye and since groups of them arise from a single infected spot this stage of the disease is sometimes known as the "cluster-cup stage." These spores are different from any yet described being one-celled, thin-walled and contain two-nuclei (the significance of which will appear later). They are produced early in the spring and are easily detached and blown about by the wind. If they lodge on wheat plants they germinate at once in the film of dew which is usually present at that time, and produce one or more long, slender tubes. These upon encountering a breathing pore on the surface of the plant immediately enter and set up an extensive growth of mycelium. This in turn gives rise in a few days to pustules of the red uredospores and the life cycle of Puccinia Graminis is complete.

Besides the cluster cups on the under surface of the Barberry leaf there appear at the same time on the upper surface of the leaf small flask-shaped organs called spermagonium. Within these, slender filaments (hyphae) arise, which form by successive abstrictions, numerous very small cells, the spermatia. It is believed by some that this is the male apparatus of the plant. As far as is known, however these spores are functionless. No one has ever been able to produce the disease in any plant by means of the spermatia. Their probable function will be discussed later in connection with the sexuality of the uredinales.

Biologic Races of Puccinia Graminis.

In the early days of the study of plant diseases, almost any rust on wheat was called Puccinia Graminis. Later it was found that there were several kinds which could be distinguished by the form, color, etc. of their spores. Besides the Black Rust, Orange or Brown Rust and Yellow Rust are commonly found on wheat and sometimes a form of Crown Rust. After restricting Punninia Graminis by these morphological distinctions it is still recorded that this species occurs on 180 different kinds of grass i.e. each of these hosts bears a rust of the essential structural features, characteristic of Puccinia Graminis. A few of these may be erroneous but the majority are well established.

In 1894 Eriksson a Swedish investigator showed that, although the morphology of the fungus on the different cereal and grass hosts varied but slightly, there was a distinct specialization of parasitism. For this reason he divided the species Puccinia Graminis into six subdivisions which he termed "formae speciales". Two of these he sharply demarcated and the remainder he considered as probably also distinct. All of these forms of Puccinia Graminis he found were capable of producing aecidia on various species of Berberis. Eriksson therefore inferred that perhaps his special forms would be equalized when grown upon the alternate host. He did not find this to be the case however and so concluded that these forms were physiologically distinct even when grown upon Berberis. In fact he was led to believe that they became more firmly fixed after a period on the Barberry.

Such an assertion naturally led to a good deal of investigation. Such men as Hitchcock, Carleton, Magnus, Rostrup, Klebahn, Dietel, Ward and Bondi, firmly established the fact that this specialization of parasitism was quite common among the various rusts.

In 1902 Eriksson made the statement that rust forms adapt themselves. Where a certain host is present in large numbers and climatic conditions are favorable changes take place in favor of the new host. The most widely grown crops would naturally be the ones on which the particular biologic forms adapted to them would attain their highest development. The fact that a rust shows particular relationships in one country does not therefore preclude the possibility of a quite different set of relationships in another country.

Eriksson also showed that closely related host forms are somewhat similar in their relation to rust. Ward (1901) in his work on the Rust of the Bromes (Puncinia dispersa) concludes that the closeness of relationship of hosts is the determining factor in the ability of the rust to pass succesfully from one host plant to another. Freeman in 1902 stated that the farther removed a species of Bromus was taxonomically from the plant serving as a host for the rust, the less probability there was of infection. Ward further demonstrated in 1903 that some forms of Brome might act as a bridging species, in enabling the rust to pass indirectly from one group of Bromes to another, although direct transfer was impossible. Salmon (1904) showed that the same thing was true for Erysiphe graminis and Freeman and Johnson in 1911 found that Barley can act as a bridging form enabling Puccinia graminis to increase its range of infecting power.

A biologic form then represents a tendency toward adaptation. This tendency may be due to various causes, the evidence being that it depends largely on the availability of host species.

As a result of his experiments Eriksson divided Puccinia Graminis into the following special forms which may be called Biological Races:

1. f. Secalis - On Rye
2. f. Avenae - On Oat
3. f. Tritici - On Wheat
4. f. Airae - On Aira
5. f. Agrostidis - On Agrostis
6. f. Poae - On Poa

Race 1. occurs on the following besides Rye - Hordeum vulgare, Hordeum murinum, Agropyron repens, Agropyron Caninum, Elymus arenarius, Bromus secalinis, etc. (These are British hosts only).

Race 2. is found not only on Oat, but on Arrhenatherum elatius, Dactylis glomerata, Alopecurus pratensis, Milium effusum, Bromus arvensis, Bromus madritensis, Festuca Injurus, Festuca sciuroides, Festuca ovina (tenuifolia).

Race 3. on wheat, also though more rarely occurs on Barley, Oat and Rye.

Race 4. on Aira caespitosa

Race 5. on Agrostis canina, Agrostis Stolonifera, and Agrostis Vulgaris

Race 6 on Poa Compressa, Poa Coesia, Poa pratensis.

Carleton in 1899, experimenting with much the same forms gave different results. According to him there are two biological races:

1. f. Tritici - on Wheat, Barley, Hordeum murinum, Koeleria cristata, Festuca gigantea, Dactylis, glomerata, Agrostis alba.
2. f. Avenae - on Oat, Avena pratensis, Avena fatua, Hordeum murinum, Dactylis glomerata Koeleria cristata, Arrhenatherum elatius, Holcus mollis, Ammophila arenaria, Alopecurus Pratensis.

Later in 1904 he adds that Holcus lanatus should probably be included in Race 1. and furthermore that there is a form of P. Graminis on Agrostis alba vulgaris which could not be transferred to Wheat or Oats.

Freeman and Johnson (1911) give a still different classification of the Biologic forms of P. Graminis: in the U.S.A.

P. graminis tritici (stem rust of wheat) on wheat and barley

P. " hordei (" " " barley) " barley, wheat & rye

P. " secalis(" " " rye) on rye and barley

P. " avenae (" " " oats) on Oats

It is evident from these results that the specialization of these races is either less strict than Eriksson would lead us to believe or else it is taking place along different lines in different countries such as Europe and America. Both of these statements may be true but in support of the former is the fact that Eriksson was able to infect Berberis vulgaris with teleutospores (sporidia from teleutospores) obtained from many grasses (wheat, oats, barley, rye Arrhenatherum elatius, Agropyron repens, Agropyron caninum, Dactylis glomerata, Agrostis stolonifera, Elymus arenarius, Poa compressa, Poa pratensis, Aira caespitosa, Bromus secalinus and many others) while Bolley was able to infect a large number of grasses with spores from a single Barberry hedge. The importance of the matter lies in the fact that if the specialization is as sharp as Eriksson points out wheat crops cannot often be infected from rust on other cereals and grasses in the vicinity. Even if such should be the case there are obviously sufficient "bridging species" to overcome the difficulty and effect the transfer indirectly.

Dr. E.C. Stakman of the University of Minnesota has done some important work in this connection, with the object of determining the possibility of developing and breaking down biological races. An outline of his method of procedure should prove of interest, since some such system will have to be employed in Western Canada, if the rust problem is to be fully investigated, for the reason that since outbreaks occur so infrequently, it would be impossible to conduct tests in the fields.

"The rusts used in making innoculations were obtained originally from their respective hosts in the fields at the University Farm, St. Paul, Minn. They were then artificially transferred to plants growing in the greenhouse. Transfers were made to new plants about once every three weeks until the rust had been confined to its own host for at least twelve successive transfer generations. In nearly all the experiments with biologic forms the rust had been confined to its own host for at least twenty generations, thus giving assurance that it was the particular form dewired.

The seeds of the host plants were planted in rich loam soil in four inch clay pots. Only ten plants were left in each pot and the first leaf of each was inoculated when six or seven days old. The plants were trimmed whenever necessary so as to leave only the one inoculated leaf on each plant. Fresh viable uredospores were used for inoculation except where otherwise specified. The spores were put on the leaves with a flat inoculating needle, which had been previously moistened in order that the spores might better adhere to the leaf surface. The pots were then placed in shallow pans filled with water or on wet sand and covered with bell jars for forty-eight hours. In nearly all cases a fine film of moisture covered the leaves during a considerable part of the time that they were under the jars. This together with a moderate temperature, made the conditions for infection ideal. After the removal of the bell-jars the plants were kept on greenhouse benches in such locations as to reduce to the minimum the danger of accidental infection."

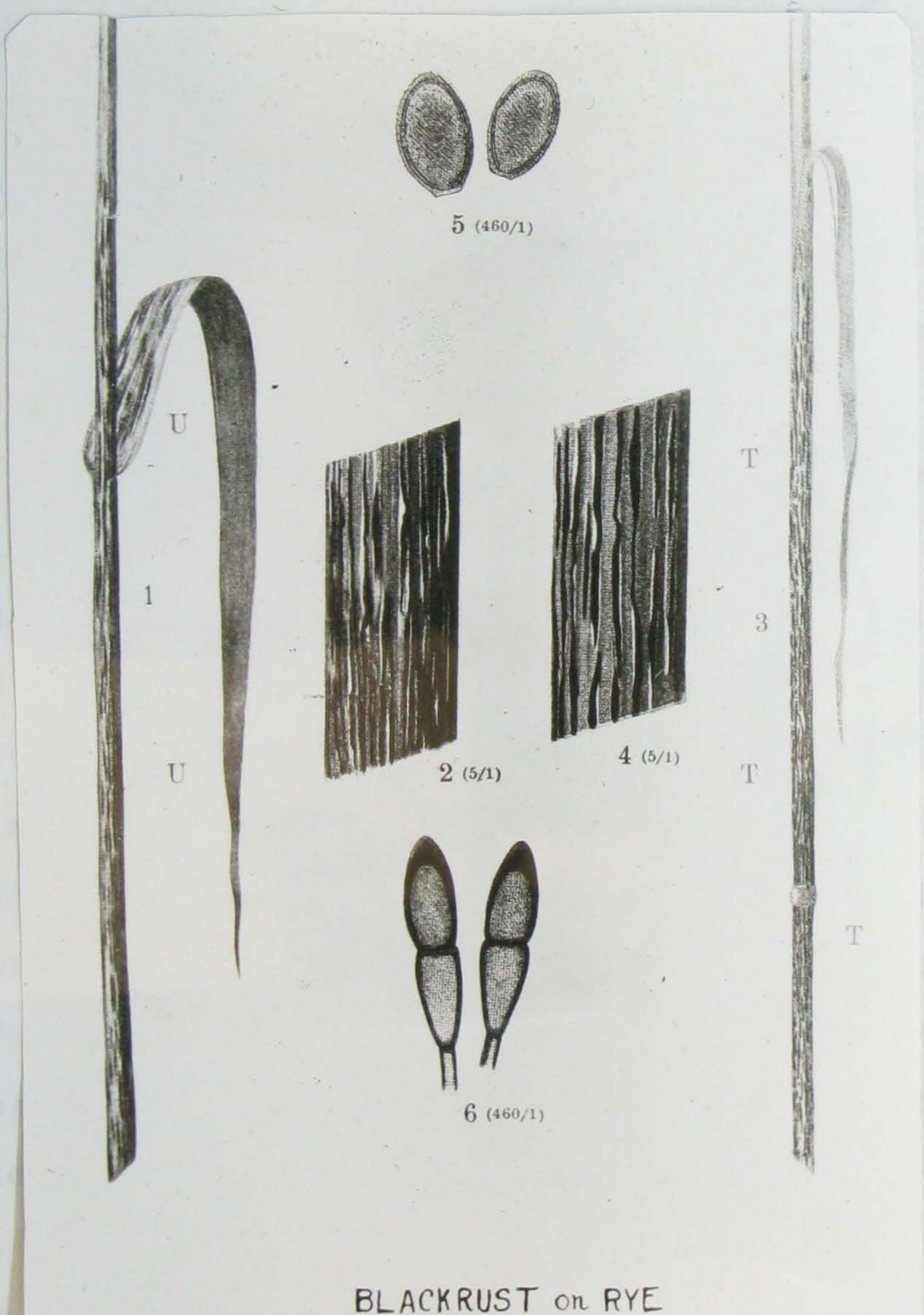
Dr. Stakman made inoculations of the various biologic forms of Puccinia graminis on different hosts (1) under ordinary conditions (2) after previously subjecting the new host to anaesthetics (ether and chloroform) (3) after leaf injury, high fertilization, etc. (in some cases).

Puccinia Graminis Hordei was tried on barley, wheat, oats and rye with the following results. Wheat and barley showed an infection of 100% in each case. Rye gave a higher percentage infection than other investigators in the U.S. have observed but was really not a congenial host. Oats under ordinary conditions were not attacked but after subjecting them to ether and chloroform the plants were slightly infected. In general the results agree with those of Freeman and Johnson (1911) for P. graminis Hordei, who state that the barley stem rust is more versatile than any of the other biologic forms of the cereal rusts, and further that the range of infection of a given form is increased after having been transferred to barley. These trials show that the stem-rust from barley in this country can pass to wheat as readily as to barley again and other inoculations show that the stem rust from barley attacks resistant varieties of wheat such as Arnautka, Khapli and Emmer quite as readily as wheat rust.

<u>Puccinia Graminis Avenae</u> in this country is supposed to infect no other cereal except oats, although it is capable of infecting a number of grasses. Carleton (1899) was able to transfer it to wheat, barley and rye. Eriksson found it on eighteen species of grasses in Sweden besides oats. Freeman and Johnson were also successful in transferring it to barley while Derr obtained direct transfers from oats to wheat and rye. Dr. Stakman found that it could be transferred successfully to any one of the other cereals but that it infects rye much more easily than wheat or barley. Anaesthetics seemed to help break down the barriers, probably due to an increased capacity for development rather than to any new ability of the rust fungus for attacking an uncongenial host. Examination ofan infected spot in the case of an uncongenial host showed dead areas of tissue. The fungus appeared to gain an entrance but could not develop in these dead areas which were due to its presence. Perhaps some toxic substance is secreted by the plant due to a certain stimulus produced by that particular fungus, which kills the tissues and thus stops the development of the fungus. The nature of resistance, however will be discussed further on.

Experiments with <u>P. Graminis Secalis</u> were not very extensive, but seemed to show that neither wheat, oats, barley nor Einkhorn are very congenial hosts, since no pustules were produced even with the use of anaesthetics.

When <u>P. Graminis Tritici</u> was tried on barley, thirty out of thirty leaves tried became characteristically infected. It would seem that these two hosts have similar susceptibilities, at least for the two biological forms P. Graminis Hordei and P. Graminis Tritici. Rye developed small pustules after infection but attempts to transfer directly from wheat to oats were unsuccessful. However oat leaves inoculated with aecidiospores derived from wheat teleutospores developed pustules on one out of fifty-six. This seems to show that the direct transfer can be made and that it is not due to its having passed through the barberry stage, since the other cereals behaved in the same way toward the aecidiospores as they did toward the corresponding unedospores. Since it is almost impossible to infect oats directly with the aecidiospores from P. Graminis Tritici an attempt was made to transfer the aecidiospores first to barley and then to use the



BLACKRUST on RYE
P. graminis Secalis

resulting uredoppores for infecting the oats. Fourth and fifth generation uredospores from barley, were used and one out of thirty-nine produced pustules and four became distinctly flecked. Infections on rye showed a slightly more severe attack after having passed through a stage on barley. Barley therefore acts as a bridging species between wheat and oats and wheat and rye, at least for this particular biologic form.

Timothy Rust

There is considerable diversity of opinion as to whether timothy rust should be considered as a distinct species or included under P. Graminis as a biologic form. In 1894 Eriksson and Henning separated it into a distinct species and designated it "Puccinia phleipratensis." Johnson considers that timothy rust in America is the same as that in Sweden and favors giving it specific rank. W.B. Grove separates it from P. Graminis on the ground that it will not infect Berberis. Kern on the other hand, thinks it should be considered as a physiological species or at most, a variety or subspecies.

Infection experiments were undertaken with this rust by Dr. Stakman and Louis Jensen (1915). They were able to transfer this rust directly to Avena Sativa, Hordeum Vulgare, Secale cereale, Avena fatua, Avena elatior, Dactylis glomerata, Elymus Virginicus, Lolium italicum, Lolium perenne and Bromus tectorum, but not to wheat. The infection capabilities of timothy rust were thus shown to be quite similar to those of P. Graminis Avenae, and more nearly like them than to any other biologic form of P. Graminis. From this close similarity it seems reasonable to suppose that it may have originated from some form of P. Graminis.

With regard to the infection of timothy by Puccinia Graminis various investigators such as Eriksson, Johnson, Mercer, Stakman and Jenson have reported negative results. Dr. Stakman and F.J. Piemeisel (1916) however by artificial inoculations were able to infect various strains of timothy with Puccinia Graminis avenae. Spores from such infections were reduced considerably in size while the pustules were small and the rust was subnormal in vigor showing that timothy is not by any means a congenial host.

Timothy grown on the Investigation Field at the University of Saskatchewan this season was badly infected with rust. The spores from this were quite similar to P. Graminis but because of their vigor of growth and size they must have been Puccinia phleipratensis. If it was this rust, it must have come from some other grass that harbors it, since timothy fields are very scarce in Saskatchewan.

Effect of the Aecidial Stage on Biologic Forms

More than one investigator has had the opinion that the aecidial stage might be able to break down biologic forms. Eriksson, as has been stated was one of these, but later came to the conclusion that biologic forms were unaltered as a result of passing through the aecidial stage on the Barberry. Arthur (1910) however concluded that the aecidial stage served as a bridging form between the various grasses. Jaczewski (1910) on the other hand did not find this to be the case with biologic forms of P. Graminis on cereals and grasses in Russia. The experiments of Dr. Stakman made in 1912 strongly support the latter view.

Teleutospores of Puccinia Graminis Tritici were used to infect barberry bushes and the resulting aecidiospores were transferred to wheat, barley, oats, rye and einkhorn . The percentages of infections obtained were practically identical with those developed from uredospore inoculations. The character of the infections were also very similar, e.g. on rye, the same chracteristic spotting and the same small abortive pustules were observed in both cases.

In 1913 the same experiment was repeated but it was found that the proportions were altogether different. On examination, it was found that Agropyron repens, badly infected with Puccinia Graminis in the teleutospore stage grew adjacent to the Barberry bushes, which had been used for inoculation. It was therefore decided that accidental infection must have occurred from this source. To prove this two barberry bushes were taken the following spring and covered with heavy muslin cages. Around one was tied some badly rusted wheat straw and that of Agropyron repens around the other. No aecidia developed on any of the check plants used. The Agropyron repens material however produced mature aecidia ten days earlier than the wheat material and in greater abundance. The aecidiospores from this material were then placed on wheat, oats, barley and rye, and the results observed. The aecidiospores from the cage containing the wheat straw gave percentages of infections on the various hosts quite similar to those produced aecidiospores which gave infections similar to those of of uredospores from Agropyron repens. Thus these biologic forms do not show any apparent change as a result of being transferred to the barberry nor is their range of infection increased thereby.

Adaptation of Biologic Forms to New Hosts.

To determine if constant association of a rust with a new host would not change its physiological capabilities, Dr. Stakman grew Puccinia graminis tritici on Einkhorn 2433. In the first few trials it was apparently one ofthe most resistant of the triticums to this rust. Transfers were made from time to time to different plants and the rust was grown on this host through successive generations for nineteen months. After one year on Einkhorn the rust was apparently much more virulent than in the original inoculation. When Einkhorn plants were inoculated with this rust and with uredospores from wheat 100% infections resulted in both cases, but the pustules from the Einkhorn rust were larger and more vigorous. Even in this short period it would seem that a certain amount of adaptation had taken place. If extended over a longer period of time it would not be hard to imagine how a new biological form might arise. Such a change would be purely the result of environment and hence could not be fixed, could not be a hereditary character. Hence it is not surprising to find that biological forms vary in different countries. The change in the fungus also seems to manifest itself morphologically as well. Wheat and Einkhorn were inoculated with spores from the same plant. The uredospores after growing for a year on wheat averaged (37.85 x 22.76 µ) while those grown on Einkhorn for a year measured (33.58 x 21.79 µ)

Other Cereal Rusts

Note.- Puccinia dispersa and Puccinia glumarum were originally included under the collective name P. Rubigo-vera D.C. Eriksson and Henning first proved in 1896 what had been long surmised, that they are quite distinct.

Puccinia Dispersa (Brown or Orange Rust)

Distribution: In Europe, Asia Minor, North America and Australia.

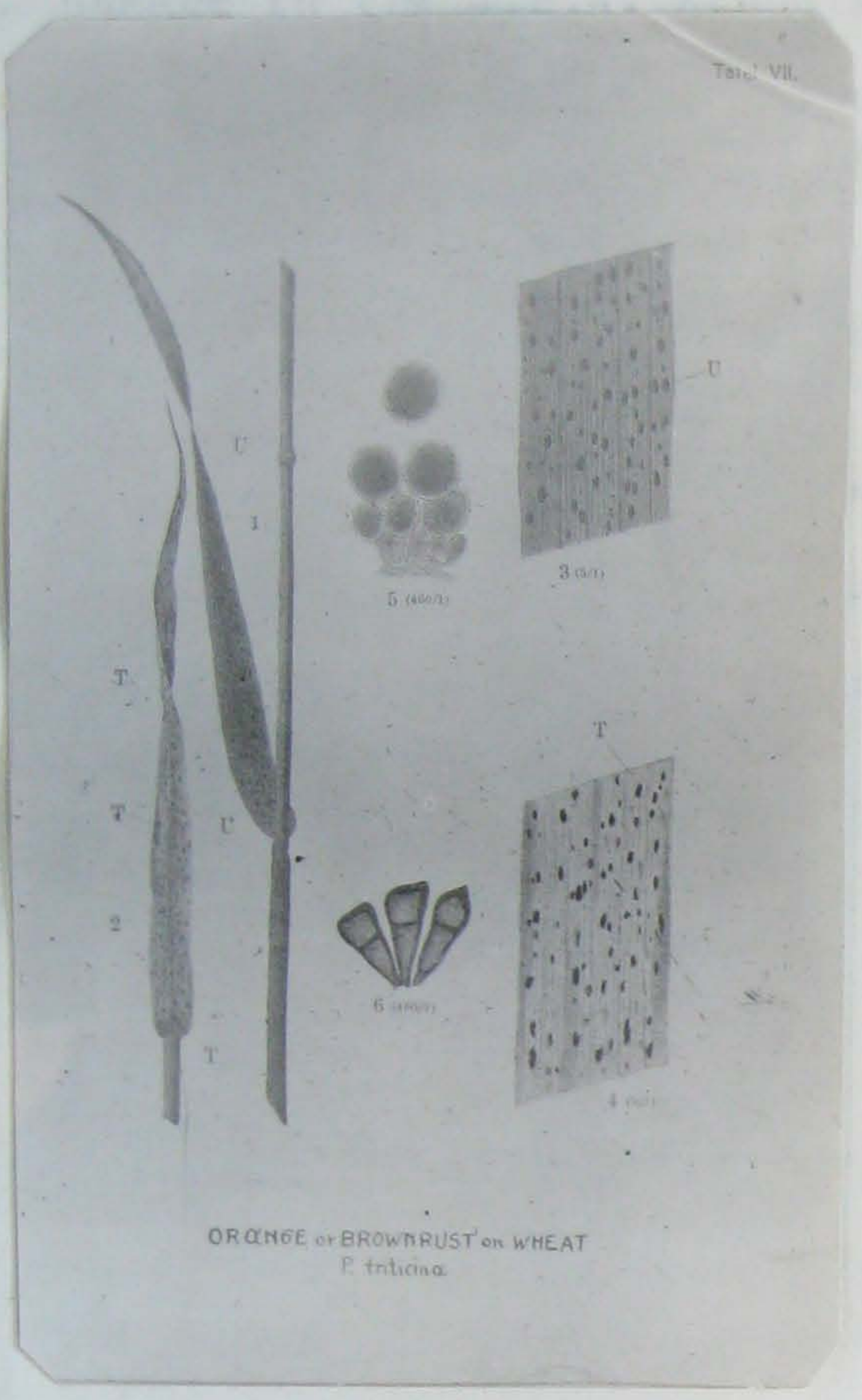
Although the general life history of this rust is much similar to that of Puccinia graminis, it differs in that some of its races do not possess an aecidial stage or else that stage has not yet been discovered. The uredospores of Brown rust can be distinguished from those of P. graminis when both occur on wheat, by being sub-globose, not elongate-elipsoid, and by the numerous germ pores which are scattered instead of forming an equatorial band as in those of P. graminis. The dirty orange color of the uredospores, caused by a brownish membrane covering the orange contents, distinguishes them from those of P. glumarum. The teleutospores have a thickened upper wall which is dark-chestnut in color the rest being thin walled and pale. They vary in shape being truncate, rounded or obtusely and obliquely pointed above.

Eriksson has divided this species into a number of forms which show certain differences chiefly biological. Although many authors prefer to consider the following biological races as distinct species, Grove adheres to this classification to save confusion in retaining the name of P. dispersa for one of them. It should be noted however that these races are distinguished almost entirely by their host plants.

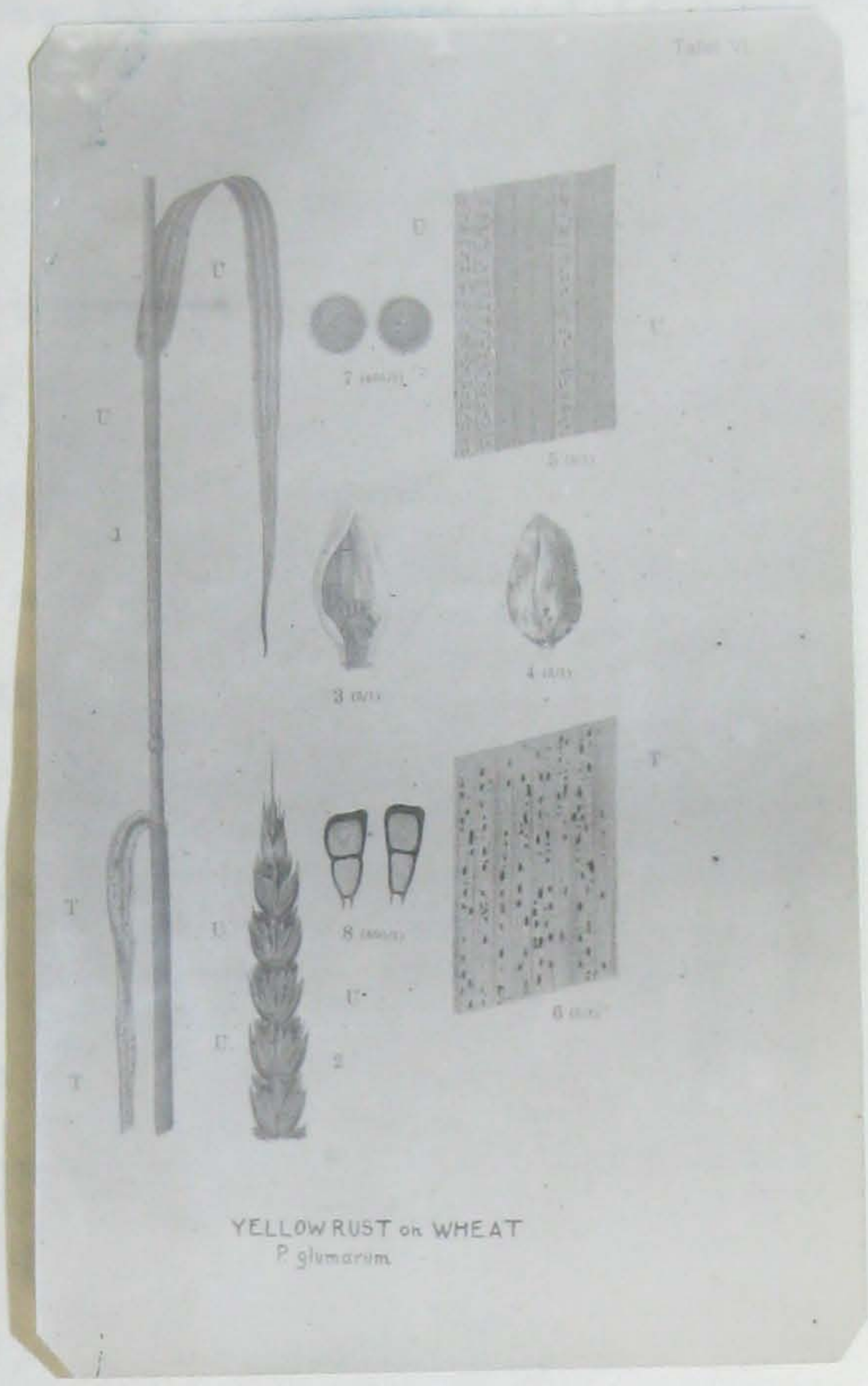
1. Puccinia Secalina or the Brown rust of rye, seems to be confined to rye in its uredo and teleutpspore stages. Sincethe teleutospores are capable of germinating as soon as they are mature, the aecidium is usually met with in August and September. This stage though very rare has been found on Anchusa (lycopsis) arvensis. Attempts to transfer this race to other plants however have been unsuccessful.

2. Puccinia Bromina or the Brown rust of the Bromes, has a life history similar to that of P. Graminis. The teleutospores germinate only after a winter's rest. An aecidial stage has been found on Pulmonaria montana.

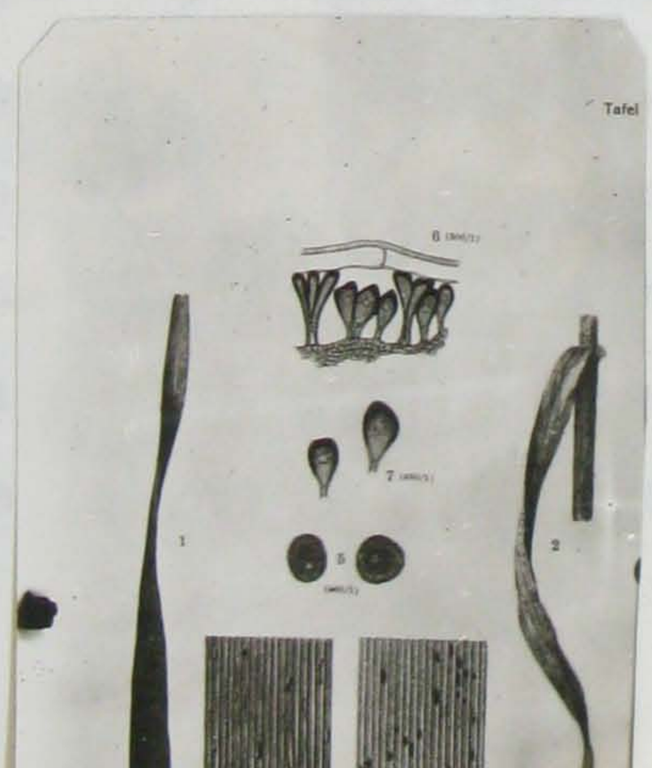
3. Puccinia Triticina or the Brown rust of wheat, also called the orange leaf-rust, is of considerable economic importance. The uredo stage appears earlier in the spring than P. Graminis. The uredosori are found chiefly on the leaves and are 1-2 mm. long and scattered without order. The teleutosori sometimes occur on the culms and are then found more or less in lines. As a rule however they occur on the under side of the "flag." (see photograph).
No aecidial stage has yet been discovered for this race although Klebahn tested the basidiospores on 42 likely species in the hope of discovering an aecidium in its life history. McAlpine of Australia has found that the uredospores will withstand the winter in that coun-



ORANGE or BROWN RUST on WHEAT
P. triticina



YELLOW RUST on WHEAT
P. glumarum



ORANGE or BROWN RUST on BARLEY
Puccinia simplex.

try, and Carleton has found the same is true in the U.S.A. south of lat. 40°N.

Bolley considers that this rust does a great deal of damage in the U.S.A., since it precedes the stem rust and if bad, completely blights the leaves. In this way much of the food manufacturing area of the plant is destroyed. There is left only the upper necks of the straw to do the starch and protein manufacturing for the plant. The time of maturing is thus greatly lengthened so that when the stem-rust arrives the plants are still very susceptible to an attack. Even in the absence of stem rust it is evident that this rust would do considerable damage by causing shrivelled kernels.

4. Puccinia Holcina. On Holcus lanatus, and Holcus mollis No aecidium known.

5. Puccinia Agropyrina. Found on Agropyron caninum and Agropyron repens. This according to Grove is one of the commonest of the rusts on wild grasses and is distinctively an autumn parasite while P. glumarum is a spring rust on the same hosts. No aecidium known.

6. Puccinia Simplex. or the Dwarf Brown Rust of barley, is found on Hordeum vulgare and other species of Hordeum. This race bears very few two-celled teleutospores but instead very numerous mesospores (one-celled teleutospores). No aecidium has yet been found but it is found in the uredo stage all year round. There is greater reason for classifying this race as a distinct species than any of the other races of P. dispersa. (See photograph).

Puccinia Glumarum

Distribution: Europe, Egypt, North America, Japan.

Puccinia Glumarum, the Yellow rust of wheat occurs to a greater extent on the glumes of wheat especially in the inner surfaces, than do other rusts. It is also found on the leaves, in long clear lemon or sometimes orange yellow lines. Besides occurring on wheat this rust attacks Agropyron Caninum, Agropyron repens, Brachypodium, sylvaticum, Bromus mollis, Elymus arenarius, Hordeum, vulgare (Barley) Secale cereale (Rye) etc. Puccinia glumarum has no known aecidial stage. It is common in certain parts of England and is called Spring Rust there on account of its early appearance, and yellow rust on account of its bright color which varies from sulphur to pale cadmium yellow. The teleutospores

CROWNRUST on OATS
P. coronifera

germinate as soon as they mature and the basidium is yellow until the basidiospores mature. No wheat bearing this rust was found at Saskatoon this year but teleutospores which closely resembled those of P. glumarium were occasionally observed in scrapings from the glumes of wheat. P. graminis, however, was found occuring abundantly on the glumes but chiefly on the outside.

Eriksson has divided this rust into five biological races, the last two of which may not be distinct since they have not been sufficiently tested as yet.

1. f. Tritici - on wheat alone
2. f. Hordei - on barley alone
3. f. Secalis - on Rye (perhaps on wheat)
4. f. Elymi - on Elymus arenarius alone
5. F. Agropyri - on Agropyron repens

<u>Crown Rust</u>

It was surmised by Plowright that there are two Crown rusts which have since been called Puccinia coronata and Puccinia lolii (= P. coronifera). They are equally widely distributed but are said to occur on different grasses, with the exception that they are both found on Holcus. Aside from this distinction of hosts they resemble each other very closely. When both occur on Holcus they can only be distinguished by maturing the teleutospores and trying if they will infect Rhamnus frangula. P. coronata has its aecidial stage on Rhamnus frangula while that of P. lolii occurs on Rhamnus catharticus (Buckthorn). W.B. Grove considers that P. coronata and P. lolii are merely biological forms of one species.

The name Crown rust is due to the peculiar projection from the top of the teleutospore resembling a crown. It is therefore easy to distinguish these teleutospores from those of other rusts. The uredospores may be distinguished from those of P. graminis by their lighter orange color and by the character of their germ pores. Both kinds of sori are generally confined to the leaves so this rust is sometimes called leaf rust (see photograph).

<u>Puccinia Lolii</u>

Distribution: Europe, Asia, North America, Australia.

This species is the one we know as the Crown Rust of oats, this being the only cereal which it attacks. It is found most commonly on Rye grass and also frequently on Arrhenatherum and Holcus. If the Buckthorne is substituted for the Barberry the life history of this rust is similar to that of P. Graminis.

Eriksson (1908) divided P. lolii into a number of biological races:

1. f. Avenae - on Avena
2. f. Alopecuri - on Al. pratensis etc.(Sometimes on Av. sativa)
3. f. Festucae - on F. elatior, and F. gigantea
4. f. Lolii - on Lolium perenne and other species (also on F. Elatior)
5. f. Glyceriae - on G. aquatica
6. f. Agropyri - on A. repens
7. f. Epigaei - on Calamagrostis epigeios (also but rarely on Avena sativa)
8. f. Holci - on Holcus lanatus.

Muhlenthaler (1910) added a ninth form to these, which occurs on several species of Bromus. Klebahn obtained fairly similar results but Carleton says that the only host of P. lolii that occurs naturally in the field in the United States is Avena sativa. He notes however that in artificial cultures under unnatural conditions, this rust may be transferred to other species. One important fact however is generally agreed upon and that is that P. lolii on Avena sativa cannot be transferred to wheat, barley or rye.

Sometimes the uredo-stage of this rust on the leaves is so abundant that the whole field will have a decidedly reddish tinge. As the plants mature the reddish spots on the leaves and leaf bases are replaced by small, greyish black spots ofthe black or winter stage. These black spots or pustules remain covered by the epidermis and are frequently arranged in circles around the old spots of the red stage. As a rule people consider that leaf rusts do not do a great deal of damage. The Crown rust of oats however is an exception as its attacks sometimes damage the oat crop very considerably. Oats at Saskatoon this season were hardly rusted at all. P. graminis was found on a few plants but no P. lolii was observed. The probable reason why oats were not attacked was that they were sufficiently early to escape the attack. What few plants were found with rust on them were in every case those which had been delayed in maturing or else volunteer growth.

<u>Rusts on Barley and Rye</u>

Under the biologic forms of P. graminis, P. glumarum, and P. dispera it has been seen that there is a form of each of these rusts which attacks barley and also a form of each occuring on rye. Puccinia phleipratensis or Timothy rust is also found on both barley and rye. The Crown rust of oats, however, occurs on neither. Both barley and rye were slightly rusted at Saskatoon this season but escaped a severe attack largely on account of their earliness.

Flax Rust.

Distribution: Europe, North and South America, Australia.

Although flax is not a cereal it is one of our important grain crops, so it might be well to consider briefly the flax rust, Melamp sora lini.

Forms of this rust occur widely on many species of Linium, and have usually been regarded as identical. The teleutospores are one-celled, at first reddish brown and later showing black. The uredospores are roundish to elipsoid and orange yellow. An aecidial stage has lately been discovered which also occurs on flax. Melampsora lini is therefore an autoecious rust. It is entirely confined to a few species of Linum. Hence infection from grasses is impossible.

If flax plants were pulled and burnt as soon as they were seen to be infected the disease might be checked, but, of course, this would be impossible on a large scale. No really immune varieties of flax are known, but fortunately this parasite does not seem to occur in the Irish flax fields.

Corn Rusts

Puccinia sorghi, the rust of corn took its place in literature about 1815. Usually it appears rather late in the season through under exceptionally favorable conditions it may develop early on the young plants. The injury caused by it however is not great. The loss occasioned is due to the destruction of green tissues and therefore the impairment of starch making power. The sori are confined mostly to the leaves and since the leaves are so large a few pustules of rust will not materially damage the plant. The uredospores are brown and are produced in linear sori. The teleutospores are black, two-celled, the cells being more or less rounded. An aecidial stage occurs on the wood sorrel (oxalis).

Sexuality of the Uredinales

The possibility that a sexual process occurred some where in the life history of rusts, was first suggested by DeBary in 1884. He said at the time, that if such a process did occur it would probably be found in connection with aecidial stage.

Perhaps it would be well to consider briefly what is taken to be a sexual union# In such rusts as P. caricis and Phragmidium this process has been clearly observed. Before the spermogones have completed their development (on Nettle in P. caricis and on the Rose in the case of Phragmidium), a mass of hyphae arises below the epidermis of the under side of the leaf pushing it outwards to form a sort of dome. These hyphae are of two kinds, an outer layer of closely joined colorless hyphae called the peridium: these meet above and roof over the dome shaped cavity. The hyphae in the centre remain shorter and give off from their upper ends parallel chains of spores, the aecidiospores. As these spores are produced one after another from the hyphae below, they burst the peridium at the summit and the edges fold back to form a sort of cup. It should be noticed at this point that the mycelium which bear the aecidiospores is continuous with that which produces the spermatia. The cells of this mycelium contain only one nucleus while the aecidiospores have two nuclei each.

If we consider the formation of the aecidia a peculiar phenomenon presents itself. The upper cell of a hypha divides into two cells, an upper sterile and a lower fertile cell, each containing one nucleus. The upper sterile cell breaks away and perishes. Two lower cells (produced in the same way) now unite to form one cell the fusion cell. This takes place by a small opening arising between the two cells which gradually enlarges until no trace of a wall is left, and the contents of the two fertile cells becomes one mass, withits two nuclei arranged side by side without fusing. This must either be an act of fertilization or a substitute for such an act.

These paired nuclei of the fusion cell now divide side by side and simultaneously (conjugate division), and a wall is formed between the two pairs and in such a way that the two nuclei

Adapted from "British Rusts" by Grove.

in the same cell are not sister nuclei. The upper cell produced by this conjugate division becomes the aecidio-mother-spore. The lower one becomes elongated in preparation for the production of more aecidio-mother-spores. By conjugate division the aecidio-mother-spore now produces a small bi-nucleated cell beneath it, which is known as an intercalary cell. This soon becomes disorganized and disappears, while the other cell becomes the aecidiospore. In this way a chain of aecidiospores, separated from each other at first by an intercalary cell, is produced. The function of the latter may be to facilitate the separation from one another of the aecidiospores and hence aid dispersion by the wind (~~see drawing~~).

The bi-nucleate condition remains in the mycelium, produced by the aecidiospores in the next host. The resulting uredospores are also bi-nucleate. Later in the season the teleutospores are produced from the same mycelium which bore the uredospores. Hence the teleutospores are at first bi-nucleate. When however a teleutospore begins to mature the conjugate nuclei unite and form one large fusion nucleus, and since the teleutospore is two-celled each cell contains one of these large fusion nuclei (~~see drawing~~). This fusion is not considered as a process of fertilization but merely as a necessary preliminary to chromatin reduction.

From consideration of the above we find that here there are three stages (which are connected with the sexual process in general): (1), the association of two (almost always non-sister) nuclei in the same cell, (2), the fusion of the two nuclei preparatory to (3) the reduction in the number of chromosomes, at any rate in the amount of chromatin matter, to the previous ordinary vegetative condition. In most of the uredinales we find that the chief vegetative divisions are interposed between (1) and (2), and (3) follows immediately after (2). The reason for this sexual process seems to be for re-invigoration. It does not seem to be absolutely essential however since McAlpine states that P. graminis in Australia maintains itself by its uredospores, on account of the absence of the Barberry.

It has been seen that the spermatia are produced by the same mycelium that bears the aecidiospores, but generally occur on the opposite side of the leaf. They are thin walled, contain little cytoplasm and no reserve material, and possess one large nucleus. All attempts to produce infection by them have failed. It would seem then that they are functionless. The only two possibilities are that they are either male gametes or conidia. Arguments seem to favor the former view such as (1) time of appearance - on the same mycelium and just before the aecidiospores, (2) their size and character - smaller than other spore forms - contain no reserve material (3) the fact that they will not reproduce the species (4) the fact that they will hardly germinate in water (5) they are sometimes accompanied by a sweet oil, which looks as if insects were intended to carry them (6) if considered as conidia, it seems queer that they should be produced just when they are least needed, while on the other hand they are missing in certain micro-forms where additional help would be most wanting. The spermatia are therefore considered by most botanists to be male gametes, that have become functionless, but this point is by no means definitely settled.

The Nature of Rust Resistance

Much has been written and many theories have been offered as to the probable nature of rust resistance. Since ancient times it has been observed that certain plants in a field of wheat are less severely attacked by rust than others. Freedom from disease however does not always mean resistance, since varieties which mature early may escape the disease and other factors may cause apparent resistance. Natural resistance only will be discussed here.

Some investigators such as Bolley (1889), Anderson (1890) Cobb (1892) Carleton (1893) have attributed rust resistance to morphological characters, e.g. hard stiff straw, smooth fibrous leaves, large percentage of silica, thick cuticle, waxy coating and small stomata. Later experimeters however have been unable to substantiate these views, since it was found that plants resistant to one species of rust are not necessarily resistant to another. Ward (1902), Bolley (1908) and Biffen (1912) decided that rust resistance was independent of morphological characters.

It was suggested by Eriksson and Henning in 1896 that resistance might be of the nature of a complex chemico-physiological nature, which is inherent and fairly constant in individual plants. Various vegetable acids were shown by Cook and Tabenhaus (1912), to have a toxic effect on parasitic fungi. Ward suggested that enzymes or toxins and anti-toxins produced either by host or parasite determined resistance. Massee (1905) attributed infection to the presence in the plant cell of positive chemotactic substances and defined an immune plant as "an individual in which the positive chemotactic substance necessary for facilitating the entrance of the germ tubes of a given parasitic fungus into its tissues, is absent." Fulton however (1906) says there is no definite chemotropic response on the part of fungi, and on the whole the evidence against the chemotropic theory is as great as for it. Hydrotropism however seems to play a part. A study of the effect of the germ-tube and its entrance into the host plant has been given much attention. Entrance into immune and susceptible varieties seems to be equally easy but when a germ tube of a rust fungus enters any but its proper host plant a struggle goes on, which results in the death of the host locally and of theparasite. The closer the relationship between the plant and the proper host of the rust the longer and more extensive will be the struggle. The more readily a rust infects a plant the less likely are these dead areas to be produced. There is certainly an antagonism between host and parasite in case of an immune or partially immune variety. Whether this be due to toxins or what only careful biochemical study will reveal. Toxins or enzymes would seem to be the only explicable way of explaining the antagonism at present. External morphology is certainly of slight importance at least in the case of ordinary stem rust. There seems to be no correlation between immunity and other observable characters such as drought resistance. Although most drought resistant wheats such as forms of Kubanka, Khapli, Iulumo are rust resistant it is also known that Kubanka 1516 and other drought resistant wheats are particularly susceptible to rust.

Immunity and susceptibility, whether due to the presence or absence of anti-toxins in the host cells, or what, have been proved to be inherited and moreover to obey Mendelian laws. This has been shown by Professor Biffen of the Agricultural School at Cambridge 1907, 1912 and by Pole-Evans 1911. They have found susceptibility to rust dominant and immunity recessive. However owing to the minute specialization which is characteristic of many rusts, a variety may be immune to one form and susceptible to another or immune in one country ahd susceptible to the same rust in another country of different climate. There seems to be a very delicate balance between host and parasite, in the attacking power of one and the resisting power of the other, which can be influenced at least to a certain extent by

Preventative Measures

Unenlightened people look upon rust more or less as a visitation sent by God and accept the damage it does as a punishment meted out by the Almighty for some offense. Even to-day there are those who say that "nothing can be done", that it is all a "matter of the wet weather causing an overabundance of sap which bursts through the stem or leaf." There are some however who realize the nature of the disease and who attempt to adopt such preventive measures as are from time to time suggested.

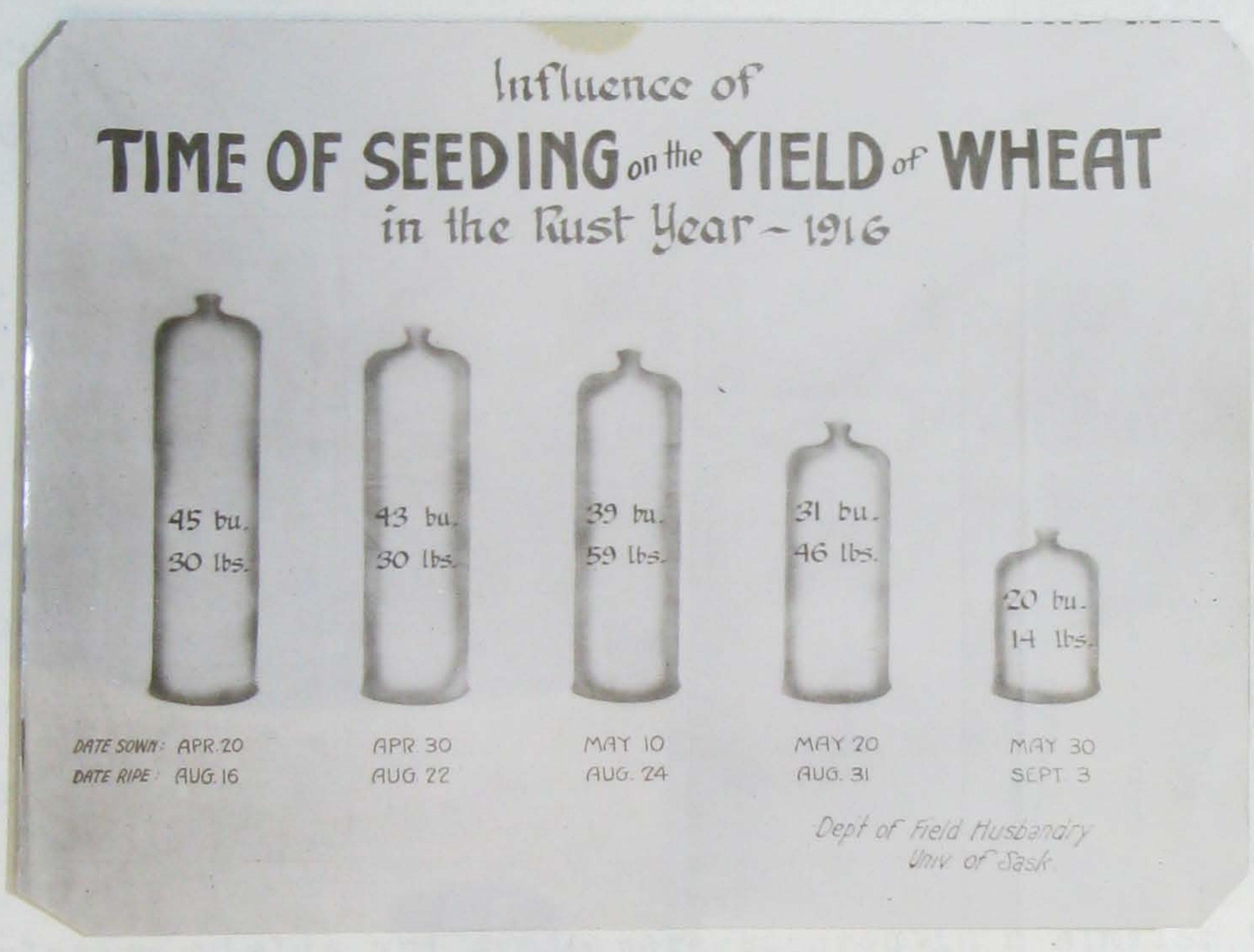
When we consider the life history of the stem-rust of wheat its method of propagation, its ability to change hosts, the fact that it is carried from one season to another independently of the seed, the ease with which the spores are carried long distances by the wind, etc. we soon come to the generally accepted conclusion that there is no single method of control like the formalin or blue-stone treatment for smut. Any one radical cure such as spraying, or seed treatment may as well be given up both because of inefficiency and of prohibitive expense. Some chemicals will kill the spores but it is altogether impracticable to use them because of the great expense it would involve.

Just as education has resulted in the general adoption of sanitary methods by civilized nations for the prevention of infectious diseases amongst animals, so must we rely on educative measures to arouse farmers to the realization that in the case of rust also "an ounce of prevention is better than a pound of cure". A combination of all preventive methods generally adopted should result in a remarkable reduction of damage done by this devastating pest. A new problem has been added to the list which the Western Canadian Farmer must meet, if he wishes to maintain the reputation he now holds - "of producing the highest quality wheat in the world."

Early Crops Escape the Rust

Early Seeding

It was a matter of common observation this year, as in other rust years such as 1904 that the earliest maturing crops of wheat were the least damaged by rust. Obviously the reason for this is, that the wheat kernels were fairly well filled before the rust obtained a foot-hold on the plants, so that the rust did not deprive the kernels


Influence of
TIME OF SEEDING on the YIELD of WHEAT
in the Rust Year – 1916
45 bu. 30 lbs.
43 bu. 30 lbs.
39 bu. 59 lbs.
31 bu. 46 lbs.
20 bu. 14 lbs.
DATE SOWN: APR. 20 APR. 30 MAY 10 MAY 20 MAY 30
DATE RIPE: AUG. 16 AUG. 22 AUG. 24 AUG. 31 SEPT. 3
Dept. of Field Husbandry
Univ. of Sask.

of as much nourishment as it would have had it had a longer period during which to work.

On the Experimental Field at the University of Saskatchewan, Marquis wheat was sown on breaking, on each of five different dates, on uniform soil, that had been broken and backset the previous year. The following figures show the value of early seeding in the rust year of 1916.

	Yield per ac.	Grade.	Wt.per.m.b.
Sown April 20th	45 bu.30 lbs.	1 Nor.	64 lbs
" April 30th	43 " 30 "	1 Nor.	63½ "
" May 10th	39 " 59 "	1 Nor (poor)	62½
" May 20th	31 " 46 "	2 Nor	61 "
" May 30th	20 " 14 "	5(Special) rusted	47½ "

All of these but the last seeding escaped frost. Similar tests conducted in rust free years showed a decrease in yield of 1 bu. per acre for each 10 days delay in seeding, whereas in this test a delay of 10 days in April caused a loss of 2 bus. per acre, a delay of 10 days between April 30th - May 10th, caused a decrease of 4 bus.per ac. and from May 10th on, a decrease of one bushel per acre, per day and a considerable lowering of grade. This decrease was largely due to rust.

These results are not those of an isolated case. The same relative yields and grades were secured in a similar "time of seeding" test carried out on fall plowed land.

Early Varieties

For the same reason that early seedings largely escape rust so do early maturing varieties. The variety which alone(at this point) successfully competes with Red Fife and has the additional advantage of being a week earlier is Marquis. In all parts of the west this year Marquis though perhaps no less resistant to rust than Red Fife, has given better results.

At Saskatoon the average yields of Marquis and Red Fife on fallow land for the five rust free years 1911, 1912, 1913, 1914, 1915 were practically the same, 29 bu - 29 lbs. and 29 bu - 21 lbs. respectively, while in the rust season of 1916 the yields were 45bu-59lbs and 38bu.-49 lbs. respectively. Pioneer andther early sort showed also a relatively higher yield during 1916, compared with other years when no rust occurred.

Crops on Loam Soils were Earlier than those on Clay Soils and Consequently were less damaged by rust.

A portion of the investigation field at the University of Saskatoon varies abruptly from a medium loam to a heavy clay. Marquis wheat was sown across this block, which was in a good state of tilth, early in the spring of 1916. The crop on the loam soil matured 11 days earlier and yielded 12½ bushels more per acre than that on the clay soil. Since equal yields were produced on these two types of soil in the rust free year of 1915 it would therefore seem as if this difference should justly be attributed to the effect of rust. Here again earliness is the dominant factor - the earlier crop (due to the nature of the soil) received the least harm.

Fallow vs. Stubble or Breaking

From various districts where rust occurred this year reports indicate that wheat on fallow land suffered more from rust than that on breaking or stubble land. This statement applies more to heavier soils since fallow crops on lighter soils may have been sufficiently early to escape rust.

At Saskatoon crops on fallow land were later than on any other preparation except perhaps those following root crops. The relative yield of fallow and surface cultivated stubble for the four rust free years preceding 1916 was 29 bus. and 19bu. 39 lbs. respectively while for 1916 it was 46 bus and 35 bus and 49 lbs. or a difference of 47.5% in the former case compared with 28.2% in the latter, and the relative yield of fallow and corn ground for 1915 was 36 bus 40 lbs. and 35 bus. 49 lbs. while in 1916 it was 40 bus. 35 lbs. and 47 bus 9 lbs. The same relative results were obtained for breaking as compared with the fallow crop. Here again the lateness of crops on fallowed land was the factor which caused the fallow crop to be more severely injured by rust.

Oats, Rye and Barley

Chiefly because oats, rye and barley are earlier than wheat, they suffered less from rust. Practically all crops on the University plots this year exceeded in yield those of 1915. On fallow the 1916 crop of wheat was 8 bu. 7 lbs. higher than the 1915 crop, while oats yielded 27 bushels and 24 lbs. and barley 30 bus and 22 lbs higher than in 1915. The winter rye crop of 1915 was badly frosted yielding only 9 bu.10 lbs. so in fairness can hardly be compared with the 1916 crop. The 1916 crop however exceeded in yield by 10 bushels any previous crop of winter rye grown at this point- under the sameconditions, and on manured fallow 20 bus. higher than ever before.

Rates of Seeding in a Rust Year

The following figures were obtained at Saskatoon:

1 bus. per acre	40 bus. 53 lbs.
$1\frac{1}{2}$ " " "	41 " 2 "
$1\frac{3}{4}$ " " "	44 " 28 "
2 " " "	43 " 23 "
$2\frac{1}{2}$ " " "	41 " 51 "

Previous to 1916 the $1\frac{1}{2}$ bushel rate has given the highest yields. This year seems to favor the $1\frac{3}{4}$ and 2 bus. rate since thicker seeding promotes earlier maturity and therefore greater freedom from rust. However the $2\frac{1}{2}$ bushel rate gives a lower yield again. It would seem therefore that there is a limit to thick seeding in a rust year. The increased crowding of the plants causes greater shade which has a tendency to keep the plants moist for a longer period after rain or dew, and since such conditions favor the germination of rust spores the increased earliness is probably counterbalanced by these factors

Conclusion

From the above data there seems to be sufficient reason to concludd that practices which promote early maturity are to be recommended as preventative measures in a rust year. It has been observed here that early seeding, packing the soil, sowing thickly, not sowing too deeply, plowing the fallow and the breaking later than usual, a well prepared seed bed and the use of early varieties, have resulted in hastening the maturity of crops. All such practices except thick seeding, have given relatively larger yields in the rust year of 1916 than in any previous rust free year. In a dry year however some of these practices would be out of the question, so each and every farmer must use his own judgment in deciding what practices are most suitable to his conditions i.e., those that will involve the least risk.

Nitrogen and Phosphorous in Relation to Rust

Professor Bracken states, from yields obtained in 1916 "that nitrogenous fertilizers and perennial legumes in the rotation each resulted in a heavier total crop, but in a lighter yield of threshed grain than did the absence of these treatments. This statement does not necessarily mean that nitrogenous fertilizers and legumes in the rotation resulted in increasing the rust damage because it is a well known fact that both of these tend to stimulate leaf and stem growth more than seed development. The application of nitrogen in the form of sodium nitrate, increased the total yield of oat straw 340 lbs. per acre, but decreased the yield of grain 7 bu. 22 lbs. Farm-yard manure increased the yield of oat straw 286 lbs. but decreased the yield of grain 8 bus. 4 lbs. On the other hand phosphorus and potassium increased the yield of straw only 93 lbs. but increased the yield of grain 1 bus. 12 lbs. per acre. We had no opportunity to observe it in our fields but it has come to our attention that where alfalfa sod was plowed in 1915, the 1916 crop of straw was exceptionally heavy, but the yield of grain was much lighter than any of several much poorer looking crops in the immediate vicinity."

In this connection O. Comes concludes from the results of many experiments and observations," that the resistance of plants to adverse conditions is in direct connection with the acidity of their sap and with the amount of tannic substances they contain. He says further that nitrogenous manuring (especially dung) while it contributes, on the one hand, in the most direct manner to the improvement of the product, chiefly by stimulating the development of parenchyma, on the other hand renders the sap more sugary with the consequence of making the plant more susceptible to the attack of parasites. In order to increase the plant's power of resistance to their enemies, the phosphatic manuring must be increased and the nitrogenous diminished. In order to obtain as much acidity as possible in plants, with a view to making them more resistant to adverse conditions, it is necessary while allowing the soil to preserve a relative degree of fertility, on the one hand to decrease the nitrogenous fertilizers, and on the other to have recourse to phosphatic fertilizers especially superphosphates which should be applied either directly of by means of green manures. Where it is necessary from the cultural point of view to use nitrogenous fertilizers, sulphate of ammonia should be preferred on account of its sulphuric acid, but the amount applied should never exceed 90 lbs. per acre. Many experimenters have laid stress upon the beneficial effects of superphosphates which generally strengthen the plants and make them resistant to parasites. This fertilizers is recognized as possessing the property, when used as a prophylactic (wards off disease) of rendering cereals rust resistant. Its good effect however ought to be attributed less to the strength it gives the plant, than to the preservation of the acidity of the sap, since the influence of anatomic structure upon the susceptibility of plants is recognized as being very slight. In other words it is not the strength of the tissues that supplies the necessary resistance to parasitic attack but the acidity of the sap, assisted by tannic substances in tanniferous plants."

Dr. E.C. Stakman conducted a series of experiments to determine the effect of the application of nitrogenous fertilizers to soils on the amount of rust developing on wheat plants grown in soils so trated. Wheat plants were grown on four different kinds of soil (1) pure sand (2) ordinary field soil (3) pure sand plus nitrogen (4) pure sand and phosphorus. The two most resistant varieties used proved to be very resistant even when they were highly fertilized. They did however show a slightly more virulent infection when grown on sand than on any of the other preparations. The differences were not great. In fact it was often hard to decide which was most severely attacked. It was observed that plants which had been under the most favorable conditions for infection were most severely attacked regardless of the fertilizer used. The difference in conditions was due to the fact that there were not sufficient bell jars to go around. In such cases the films of moisture on the plants were not so persistent and it was noticed that there was a marked freedom from rust in such cases. Had these plants been allowed to grow longer it is quite probable that those fertilized with nitrogen would have become more severely rusted while those fertilized with phosphorus would have been slightly less affected. He attributes this not to the specific action of the chemicals on the rust fungus but rather to their effect on the general condition of the plant, andin the field on the immediate atmospheric conditions.

To determine more accurately whether there was a direct effect of substances in the soil on the amount of rust, wheat was grown on a nutrient media to which nutrient salts were added as follows:

1. Potassium nitrate: 2 grams per 1000 cc.
2. Calcium phosphate: 3 grams per 1000 cc.

3. Potassium nitrate; .05 grams per 1000 cc.

4. Calcium phosphate; .075 grams per 1000 cc.

The wheat used was Minnesota No.163. All inoculations were placed under bell jars and subjected to uniform conditions. This experiment was performed two times and the order of virulence each time was 3,2,4,1. After three weeks there was very little difference between 2,4, and 1 but 3 was very much more virulently attacked. It would seem therefore as if an excess of nitrogen does not necessarily in itself cause an increase in the amount of rust and an excess of phosphorus does not diminish it very appreciably.

He summarizes his work thus: "That the absence or presence in excessive amounts of various nutrient substances such as nitrogen and phosphorous salts does not directly affect the immunity or susceptibility of wheats. Conditions favoring a normal development ofthe host are conducive to a vigorous development of rust. The action of fertilizers either natural or artificial is probably indirect. Temperature conditions and relative humidity are probably more important than soil conditions."

From this work it would seem that excess nitrogen in itself does not make a plant more susceptible to rust. Under field conditions however, since crops grown on soils rich in nitrogen are ranker and more succulent in growth than crops grown on normal soils or those rich in phosphorus but not in nitrogen, they are for that reason more likely to be severely attacked by rust. Dense growth will tend to cause greater shade and hence moisture will be longer in drying off the plants This factor would not show up under artificial conditions such as were employed in the above experiments. If the plants on the nitrogen soil were more severely attacked it might therefore be attributed to a more sugary sap but since they were not itwould seem that this does not materially affect resistance and since the plants on the phosphorus soil did not show any greater resistance than the other treatments it would look as if the acidity of the sap had very little to do with immunity. This point however will still bear further investigation. Since we know that crops grown on soils rich in nitrogen produce a heavier growth of leaf and stem and are later in maturing, we would expect them to be more severely attacked by rust. As a preventative measure then the farmer should not depend too much on soils rich in nitrogen.

Various salts such as copper sulphate, copper carbonate and iron sulphate, used in media, in which wheat plants were grown did not seem to confer any greater degree of immunity upon the plants.

Resistant Varieties

Probably the most promising means of combatting the rust disease is by the use of resistant varieties of wheat, oats, barley, etc. More attention so far has been paid to wheat. At various experiment stations in the U.S.A. it has been observed the Durum wheats are more successful in combatting rust than any of the common wheats grown. This was probably the most important observation from the rust season of 1904.

Kubanka the leading variety of Durum or Macaroni wheat has been grown on the trial plots at the University of Saskatchewan for six years During that period it has given practically the same yield on fallow as the standard varieties Marquis and Red Fife. Although not entirely resistant to rust it is much more so than any other variety of common hard spring wheat grown at this point. This is well shown by the 1916 yields, when it yielded 12 bus. 4 lbs. more on fall plowed land and 1 bushel 6 lbs. more on breaking than either Red Fife or Marquis.

Two rows of Kubanka were used as a border around foundation beds of Marquis, Red Fife and Taylor's Wonder. While all three of the varieties within were fairly well covered with rust, this border remained untouched even though the plants were more succulent and later than those within, due to having a large area of ground per plant from which to draw nourishment and moisture. This therefore indicates clearly the rust resistance possessed by this wheat. Had it even been as susceptible as the wheat within one would have expected it to be more severely attacked.

Besides resisting rust, Kubanka shatters less readily than Marquis, and is resistant to drought. On the other hand it is inferior to Marquis as a milling wheat, both because of its greater hardness and because of the yellow color of the flour made from it. The bread from such flour is highly nutritive and palatable but smaller in volume and more yellow in color than that from Marquis -- due to the low quality of the protein which it contains. It is valuable for making macaroni and for blending with other wheats for flour purposes. In the U.S.A. the price is practically the same as for common hard spring wheat but at present a market for it in any quantity does not exist in Canada, and since the Canadian farmer cannot as yet meet the

10 per cent tariff into the States, Kubanka can hardly be here recommended at present. It may some day in the near future have a place in the south-west of this province.

Besides the Durum wheats certain of the Emmers are also particularly resistant to rust. They are not so important however since they can only be classed as feed wheats. They retain the hull after threshing, are early, short strawed, bearded wheats and are more or less resistant to drought.

The following figures obtained this year in North Dakota give some idea of the relative resistance to rust of different varieties of wheat. One feature was noticed there particularly this year, and that was that different strains of Durum wheat varied considerably in their ability to resist rust. A few strains were reported as being badly rusted.

	Variety	% Infection.
Common Wheats	Marquis	75%
	Minnesota 163 (Fife)	65%
	" 169 (Bluestern)	70%
	" 188 (Preston)	80%
	Ghirka Spring	85%
Durums	Peerson Rust Proof	40%
	Yellow Gharnouka	60%
	Arnautka	50%
	Kubanka 1440	45%
	Kubanka 4063	65%
Emmers	Emmer 1524	Trace, remarkably clean
	Emmer 1526	" " "
	Khapli 4013	" " "

In striking contrast to Kubanka 1440, 4063 and other Durum wheats is S.D. No 284 a selection recently made by Champlin from Kubanka 1516. During 1916 this strain has proved to be a high yielder, a good milling wheat and shows great rust resistance. At Brooking's Experiment Station S.D. this year it showed only 5% stem rust as compared with Yellow Gharnouka 20%, Kubanka 1440 25-30%, Arnautka 30% and Marquis 45%. This strain particularly might be used to cross with our common wheats to give them greater rust resistance. Marquis was less damaged by rust here, chiefly on account of its earliness. The above figures show that it does not possess any outstanding immunity to rust.

Reports from the States where oats were badly rusted, indicate that the early sorts such as Sixty Day, and the earlier sowings were much less injured by rust than later sowings and later varieties, such as Garton's No.5, Ligowo C.I. 599, Gene Naked C.I. 764 and Swedish select C.F. 717.

Professor Zavitz of Guelph gives a five year average (1910-1914 inclusive) of % rust on straw, no. of days in reaching maturity, and yield of grain per acre. for each of eight varieties of oats, three varieties of six-rowed barley, and ten varieties of winter wheat:

Varieties	No. Days Maturing	Bush. Grain per acre	% rust on straw.
Oats:			
Early Ripe	110	66.6	6
Daubeney	102	66.0	6
Siberian	109	84.5	7
Banner	111	67.1	9
Tartar King	108	70.3	12
Abundance	109	82.3	14
Storm King	108	64.7	16
Black Tartarian	105	54.6	21
Barley			
Mandscheuri	100	61.9	2
Mensury	97	47.4	4
Zulu King	98	54.9	6
Winter Wheat	Aver. Date of Maturity		
Kharkov	July 26	47.3	4
Tuscan Island	" 25	41.1	5
Banatka	" 27	42.0	6
Turkey Red	" 26	38.3	7
Imperial Amber	" 24	45.4	9
North Wester	" 25	39.5	11
Treadwell	" 26	33.5	12
Grand Prize	" 26	42.6	14
American Wonder	" 24	40.1	
Abundance	" 25	39.3	17

Destruction of the Barberries, Buckthorns and Wild Grasses.

It is now known that the stem rust of wheat, Puccinia graminis can live from year to year without the Barberry and Freeman and Johnson state, that they have grown uredospores for two years without loss of vigor. On the other hand many investigators have noticed that where the barberry bushes grow the severity of rust in the immediate vicinity is much increased. In fact Prof. Bolley states that he has been able to trace the effects of a single Barberry hedge for miles in the direction of the prevailing winds. Whether this increase in vigor is due to the sexual process that occurs or not, is hard to say, but such evidence would point to that as the cause. If the uredospores from Barberry infection are more vigorous one would naturally expect a more virulent form of the disease both in the vicinity of barberry bushes and as well after they had been carried long distances by the wind.

The common Barberry (Berberis Vulgaris) is a native of Europe found wild in many localities especially in the east. In the west it is not found to any extent, except perhaps on lawns here and there. This plant is a spring shrub 6-9 ft. high, with yellow wood, arching branches and grey twigs. The leaves are bright green, smooth somewhat oval, from one to three inches long, the margins having bristly teeth. The flowers are small, yellow and borne in long drooping clusters (racemes). The berries are oblong, red, and sour. The purple-leaved variety (Berberis vulgaris, var. atropupurea, Rgle) is similar, except that the leaves are dark purple. If Barberries are required for ornamental purposes the Japanese Barberry (Berberis thumbergie, D.C.) may be planted as this species is not attacked by Puccinia Graminis.

The following species of Barberry are known to harbor the aecidial stage of stem-rust.

Species	Native Range.
Berberis aristote	Himalayas
" emarginata	S.Europe to Himalayas
" canadensis	Alleghanies
" vulgaris	Europe to East Asia, naturalized in America
" aquifolia	British Columbia to Oregon
" repens	Western North America
" neubertii	Garden Origin

There may be other hosts for the aecidium of this rust but so far searches by botanists have been unfruitful. It is very probable that no other aecidial host exists.

At one time it was thought that all we needed to do to rid ourselves of stem rust was to eliminate all members of the Barberry family. When it was found that this rust could get along without an aecidial stage the problem was again as great as ever. If we intend to combat it however we must use every means at our disposal to lessen its ravages. If the Barberries are instrumental in increasing the virulence of the disease we should then be justified in destroying them as a preventative measure. At the best we would only be losing a thorny shrub which has plenty of equally good and much less dangerous substitutes and we would have a chance of seeing what the result would be. Ontario has passed a law providing for the uprooting of barberry bushes within a limited period, and imposes a fine of $10. for planting or selling such. Only a step such as this will result in very general good to the whole community.

The shrub which harbors the Crown rust of oats, i.e. the Buck Thorn (Rhamnus cathartica, L.) should receive similar treatment. This rust though not so dangerous as the former, should be controlled as much as possible. The Buckthorn is also a native of Europe. It is from 6-18 ft. high and is used for hedges and ornamental purposes. The leaves are glossy, ovate and green and the flowers small and inconspicuous being greenish in color. The branches are thorny and the berries spherical black in color and very bitter in taste.

Wild grasses and weeds should be kept down, not only as a clean farming practice but also to lessen the damage by rust. It has been shown that Puccinia Graminis and other rusts flourish on many wild grasses and from these can be transferred to the wheat fields. Puccinia Graminis was noticed to be very abundant here this season especially on Wild Barley (Hordeum jubatum) and on many native wheat and quack grasses. The destruction of such plants should materially lessen the number of spores produced and hence the damage done to the wheat crops. It may also be the case as will be mentioned later that these grasses serve to carry the disease through the winter.

Value of Rusted Wheat for Seed

The first concern of thefarmer in using rusted wheat for seed is the danger of transmitting the disease to the resulting crop. Can rust like smut be carried by the seed?

Most investigators have been unable to show that such is the case, but Pritchard in 1911 found mycelium resembling that of P. Graminis both in the pericarp of wheat grains and in various parts of wheat seedlings. He showed that large numbers of wheat grains contained pustules both of teleutospores and uredospores under the bran layer. He proved that the mycelium from the pericarp penetrates through the intercellular spaces, as well as through the cells and soon passes into the spaces between the leaf-sheaths where it grows rapidly and attacks the tissues at various points. It would certainly be a simple matter for the seed to become infected seeing that the surrounding glumes are often badly attacked and from here it could easily enter the seed in its soft condition before maturing. If this state of affairs prevailed on a larger scale it would seem to be one explanation of the origin of rust outbreaks.

On the other hand Professor Bolley has sown seed thus infected in glass cages, properly ventilated but proof against spore entrance and compared with similar seed sown on an ordinary plot. Plants in the former case were untouched by rust while in the latter they became badly infected. It would therefore seem as if the infection came through the air (as a general rule) and not through the seed. This experiment was performed in 1898 and repeated in 1905 with similar results. Some may say that these cages may not give a sufficiently normal growth of the wheat plant to support that of the parasite. This seems hardly probable since in ten days after the cages were removed all these plants were thoroughly broken out with rust, and again, smut which is known to be carried by the seed, developed within some of the cages, showing conditions were at least favorable for that parasite.

Another theory known as Eriksson's Mycoplasm theory has been advanced to explain the origin of rust outbreaks. His hypothesis states that the protoplasm of the fungus is present in the grain mixed with the protoplasm of the host in such a way that the two are indistinguishable. As the plant grows he assumes that the two grow together until at a certain time, the protoplasm of the fungus separates itself from that of the host in the form of "nucleoli" passes into the intercellular spaces through "invisible pores", then or earlier surrounds itself with a cell wall, forms a mycelium and begins its ordinary life by producing uredo-postules. This is a very indefinite hypothesis and its originator has had to encumber it with subsidiary hypotheses to explain various objections. Many of his hazy observations are unsubstantiated and many experiments point to the improbability of it.

Jaczewski (1910) grew seeds from much-rusted plants in glass cages well protected from outside infection and was unable to produce rusted plants. Linhart, Zukal and Klebahn had similar results. This would seem to indicate that there is little danger of sowing seed from rusted plants and Bolley's work that there is little danger from sowing seed containing the mycelium and spores.

By far the greatest danger would therefore seem to come through the air rather than through the seed. Many experiments and observations show that under atmospheric conditions favorable for rust development, rust epidemics will occur regardless of the source of the seed. So far as danger of infecting the next crop I should consider of quite minor importance and proceed to select my rusted wheat for seed just as any other shrivelled seed, such as that resulting from drought. It is generally known that shrivelled seed due to drought or immaturity unless to an extreme degree is fairly safe to plant. The same may be said of rusted seed. Germination tests conducted at this Station and at other points have shown that rusted wheat as a rule germinates freely. The vigor of growth from the shrivelled grain however is found to be much inferior according to its condition than plants grown from plump seed. The percentage germination cannot therefore be taken as a guide in determining the value of rusted grain for seed.

Since rusted grain is shrunken there will be a larger number of kernels per bushel, and with the fairly high germination of rusted wheat, more plants will grow per acre, if sown at the usual rate, than if plump seed was used. The farmer may realize this and think himself safe in sowing such seed. Another factor and the most important however must be considered i.e. the vigor of growth. Shrivelled kernels have less nourishment to start the young plant with and as a result the seedlings will be weak and will soon drop behind the more vigorous plants from plump kernels. The reason for this is evident -- the plump kernel has sufficient nourishment to keep the plant growing for several days until it develops a sufficiently strong root system to enable it to obtain its food from the soil. On the other hand the must depend on its tiny roots to get the rest from the soil. If adverse conditions such as frost or drought prevail at this time it is very doubtful if the seedling from the shrivelled kernel will recover. If it does only weak poorly developed plants will result. The plump kernel will produce a strong vigorous plant with sufficient vitality to withstand and recover from considerable frost or drought.

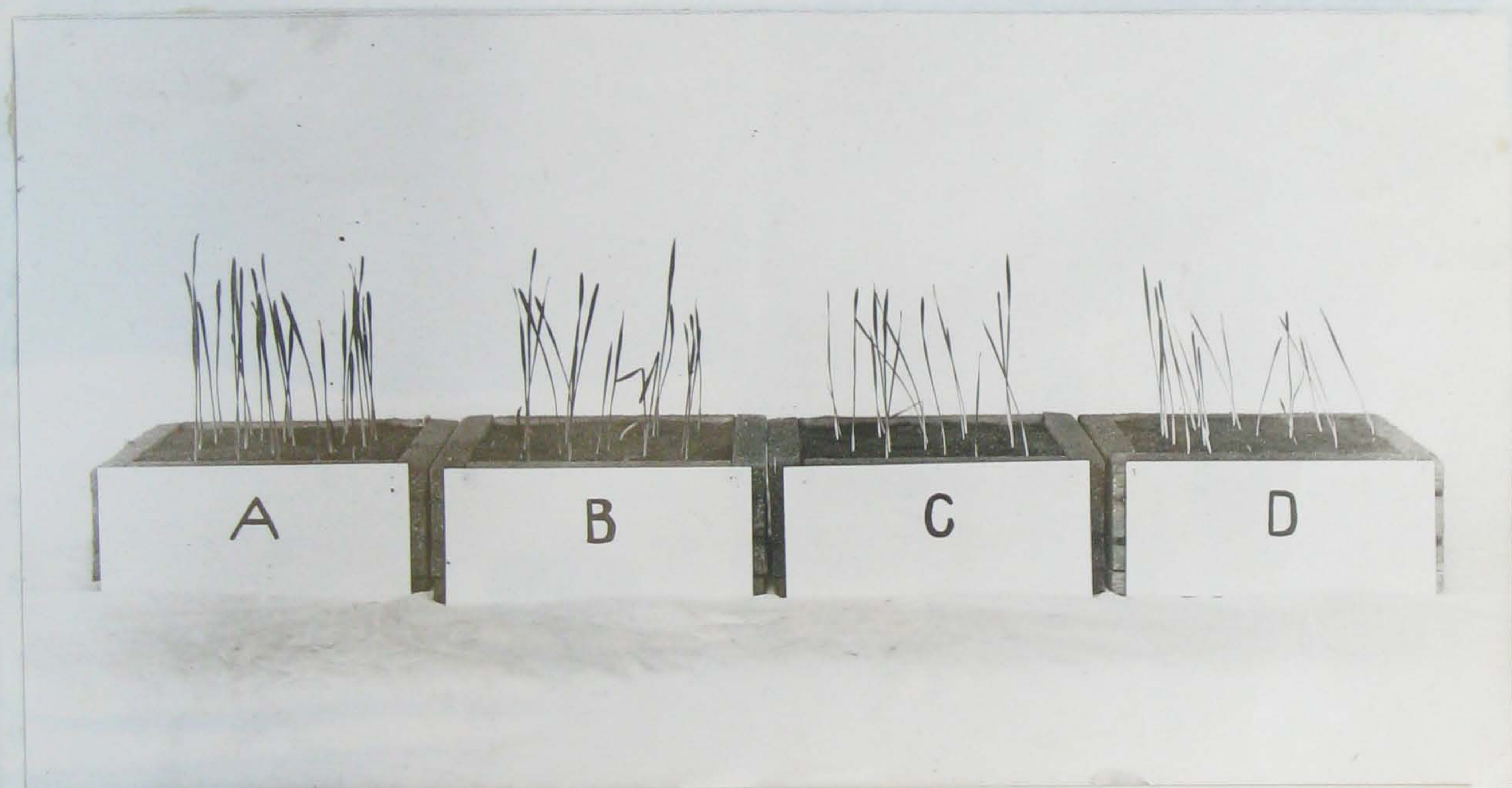
One cannot therefore rely on the weight per measured alone, in determining the value of rusted wheat for seed. Wt. per measured bushel, plumpness and freedom from injury indicate quality in seed but perhaps the safest indicator of vigor of growth is the weight per kernel. Farmers who would be successful in this country cannot afford to take chances. If they sow shrivelled seed they are taking great chances, whereas if they sow plump seed they are doing all in their power to insure a safe crop. The wise farmer will pursue the latter course.

There are few farmers who do not produce sufficient plump seed in a rust year to serve as seed for the next crop. Those who do not must purchase from those who do. If a farmer has avariety suitable to his farm and can obtain sufficient plump kernels from it for seed, he is far wiser to do so than to purchase from elsewhere.

It is evident that if there are kernels in a crop which are plumper than others, these kernels must have been produced by plants which were not as badly attacked by rust as others i.e. more resistant to rust. By screening out the shrivelled kernels with the fanning mill and using the plump seed the farmer is selecting his seed for rust resistance. It is true that some of these kernels may come from plants which escaped rust for other reasons such as early maturity. Even so ,plants from such seed will be more likely to escape rust again than those from shrivelled seed. The result of sowing badly shrivelled kernels as compared with plump ones is well illustrated by the following photographs of Marquis Wheat.

Photograph No.1. shows the seed that was sown, Photograph No.2 the plants from this seed eight days after planting, Photograph 3 shows the same plants eight days later. It should be noted that all samples were grown in pure sand, both to provide uniform conditions and also to show which sample would withstand poor soil con-ditions the best. Sample A was grown at the University and matured early thus escaping most of the rust. B,C and D were badly rusted

No. 1



No. 2

coming from North and South Dakota:

Sample	A	B	C	D
Wt.per meas. bu.	64	50	42	36
No.seeds per bush. in 1000's	1372	2830	4110	5361
% Germination	96%	(82%) 72%	(83%)80%	(89%) 76%

(The figures in brackets indicate the % germination of the plumpest kernels selected from each sample)

No.of germinable seeds per bushel in 1000's	1317	2037	3288	4074
Wt. of 1000 kernels	32.975 g	15.985 gr	11.005gr.	8.438gr
Grade	No.1 Hard	No.5Special	Feed	Feed

Sample B contains nearly twice as many germinable seeds per bushel as A.With judicious cleaning it might yield sufficient plump kernels for seed but it is very questionable if it should be used even then.C. and D are certainly out of the question for seed, even though they contain several thousand more germinable seeds per bushel. Perhaps the most outstanding feature illustrated by these photographs is the vigor of growth. After eight days growth there is not a great deal of difference in the stand but the next week "tells the tale." Plants from the shrivelled seed have gotten all the nourishment possible from the seed and are in a weak condition. Should they encounter frost at this time they would have a pretty poor chance of recovering. On the other hand the No.1 Hard plants stand up quite strongly, showing what a good start the extra nourishment in the seed has given them. B, C and D have fallen off in the last week instead of gaining because their source of food-supply is exhausted. A, however has gained considerably. It is clearly evident that the farmer should sow seed which approximates the No.1. Hard sample as nearly as possible. The nearer to this standard the safer will be his crop. Should we have conditions which favor rust this year again crops from shrivelled seed are bound to be the worest attacked since they get a later start and hence will be longer in reaching maturity.

If a farmer was guided alone by % germination in choosing seed, C and D would have been placed before B which certainly would have been unfair. The safest guide to the important factor - the vigor of growth - is the weight per kernel, or weight per 1000 kernels. A germination test such as the above should be made by every farmer. If uniform soil, such as sand be used the vigor of growth should be well illustrated.

From observations made in the rust seasons of 1904 and 1905 Professor Bolley makes the following statement. "Our experiments and observations during the seasons of 1904-and 1905 teach plainly that no matter what the variety of wheat or what the sample it does not pay tp plant the light weight seeds. They should be graded out. The heavy weight seeds ofthe same sample always excelled the light weight seeds in growth from start to finish, as well as in yield and quality production. Our tests also showed that heavy weight seed graded from a rusted crop excelled in yield heavy weight seed of the same variety which had not been subjected to rust attack the previous season. Heavy weight wheat graded from a badly rusted crop shows markedly greater resistance to rust than either the wheat from rust shrivelled seed or that which grew from plump seed of the same variety imported from a non-rust region. Many farmers of the state observed this faature in the crop of 1905." According to this the farmer who grades the plump kernels out of his crop this year, for next year's seed is protecting himself against rust should it accur in 1917. This resistance is not the result of the seed having been subjected to rust conditions but rather to its having been produced by rust resistant plants. Such resistance may not be transmissable year after year but constant grading each year, (especially where rust occurs frequently) is likely to at least maintain the standard of rust resistance of the particular variety used.

Other Pertinent Questions

Time to Cut Wheat in a Rust Year

Besides the question of whether rusted seed should be used for seed, several other difficulties have arisen which as yet have not been fully investigated. Because rusted wheat took longer to ripen many farmers were undecided as to whether they should cut it while still green or leave it until ripe. Some were advised to cut while the wheat was still green so that the rust would be stopped from developing and so the kernel could continue to fill from the sustenance in the straw. Others were advised to leave the grain standing until fully matured saying that the grain would receive whatever sustenance that was not used up by the rust.

We have found that under the rust conditions that prevailed at Saskatoon this year the latter treatment gave the best results, i.e., where the grain was not in danger of frost as a result of standing and where the rust epidemic was not particularly virulent In districts where the crop is very badly rusted so that no more nourishment is likely to be carried to the grain it is questionable if leaving it would be advantageous. The brittle condition of the straw caused by the rust and other conditions might cause greater loss by leaving. In such cases however it would probably make little difference which method was pursued. If not badly rusted and in danger of frost by leaving, it would probably pay to cut green.

An experiment was conducted in this connection with three varieties of wheat, Marquis, Red Fife and Taylor's Wonder. The object was to see if any gradual development of the kernels took place from the time the grain was in a green state until it was fully ripened, under rust conditions. It must be noted however that none of the material was very badly rusted. If it had been, such large yields would not have been obtained.

Ten plants of each variety were taken every day, from plots located side by side, in which the plants were grown under unifor conditions, every seed being planted at the same depth and the same distance apart. Care was taken not to select plants which were particularly favorably located such as near the outside of the plot or adjacent to a miss. The material was then examined under the following headings:

Red Fife ~~Marquis~~

Date Pulled	Stage of Dev'l't	Rust Cond.	Total wt. of seeds.	Wt. of 1000 kernels.	Plumpness
Aug.17	Soft dough	med.	21.240	26.784	badly shrunken
" 18	" "	"	35.694	26.245	" "
" 19	" "	med.to bad	35.140	31.772	fair
" 20	" "	med	36.312	30.617	"
" 21	" "	"	23.694	27.325	a few plump kernels
" 22	med. "	"	39.320	31.710	fair
" 23	" "	"	33.648	29.361	quite badly shrunken
" 24	" "	bad		31.803	fairly plump
" 25	" "	med.to bad	31.150	34.611	" "
" 26	firm "	med.	28.524	32.975	" "
" 27	" "	med.to bad	34.127	34.402	" "
" 28	" "	" "	32.637	33.337	consid. shrunken
" 29	" "	" "	31.145	34.642	quite plump
" 30	hard "	rather bad	38.115	33.028	consid. shrunken
1915	" "	no rust	45.639	33.095	good

The total weight of seeds correctly represents the relative yields per acre. A considerable difference is noted between the first and last dates both in the total weight of seeds and in the weight of 1000 kernels. A gradual increase from day to day does not occur however, nor would we hardly expect such to be the case where such a short period intervened between the taking of the various samples. For this reason an average of the first three, the middle three and the last three dates of pulling and also of the first five and the last five dates were made.

Red Fife

Dates.	Total wt. of seeds or approx. yield in b.p.a.	Wt. of 1000 kernels.
17,18,19	30.691	28.267
23,24,25		31,925
28,29,30	33.965	33.682
Gain by leaving till ripe	3.274 b.p.a or 10.66%	5.415 grams or 19.16%

This shows both a gain in yield and in the quality of the grain as shown by the weight of 1000 kernels. If such grain had been cut in the green state, as some were advised to do, this would have been the loss. It would therefore certainly pay in this case to leave the grain standing until ripe, provided such a delay would not seriously inconvenience other operations and provided there was no danger from frost. An average of the first five and the last five dates show a similar gain.

Dates	Total wt. of seeds or approx. yield in b.p.a.	Wt. of 1000 kernels.
17,18,19,20,21	30.470	28.548
26,27,28,29,30	32.910	33.685
Gain by leaving till ripe	2.44 b.p.a. or 8% gain	5.137 grams or 17.99%

A chemical analysis of the grain for protein of two of the dates of pulling (a week apart) shows a considerable increase of the protein in the grain in that short time. The protein in either case however is not as high as the grain from the unrusted crop of 1915.

		Total Protein
Red Fife Rust Free 1915		7.836
" " Pulled August 20	1916	6.141
" " " " 27	1916	6.572

The accompanying photographs No.4 and 5, shows a considerable increase in vigor of growth, by leaving the grain standing nine days (Aug.17 to Aug.26) but not much difference in per cent. germination. The fact that the grain from the last cutting shows a greater vigor of growth again shows that it contains more nourishment than that from the earlier cutting. ~~Photograph No.4 shows the samples eight days after planting while No.5 shows the same samples eight days later again.~~

The figures for Taylor's Wonder are as follows:

Taylor's Wonder

Date Pulled	Stage of Development	Rust cond.	Totalwt. of seeds	Wt. of 1000 kernels	Plumpness.
Aug.17	soft dough	bad	35.184	35.504	slightly shrunken
Aug.18	" "	"	31.776	33.985	" "
" 19	med. "	"	40.681	36.322	" "
" 20	firm "	"	38.710	36.866	fairly plump
" 21	" "	"	42.977	37.146	" "
" 22	" "	"	33.039	35.526	" "
" 23	" "	"	43.551	35.436	" "
" 24	" "	"	35.799	36.492	" "
" 25	hard "	"	41.731	36.130	quite plump
" 26	" "	"	39.751	36.806	" "
" 27	" "	very bad	45.082	37.662	" "

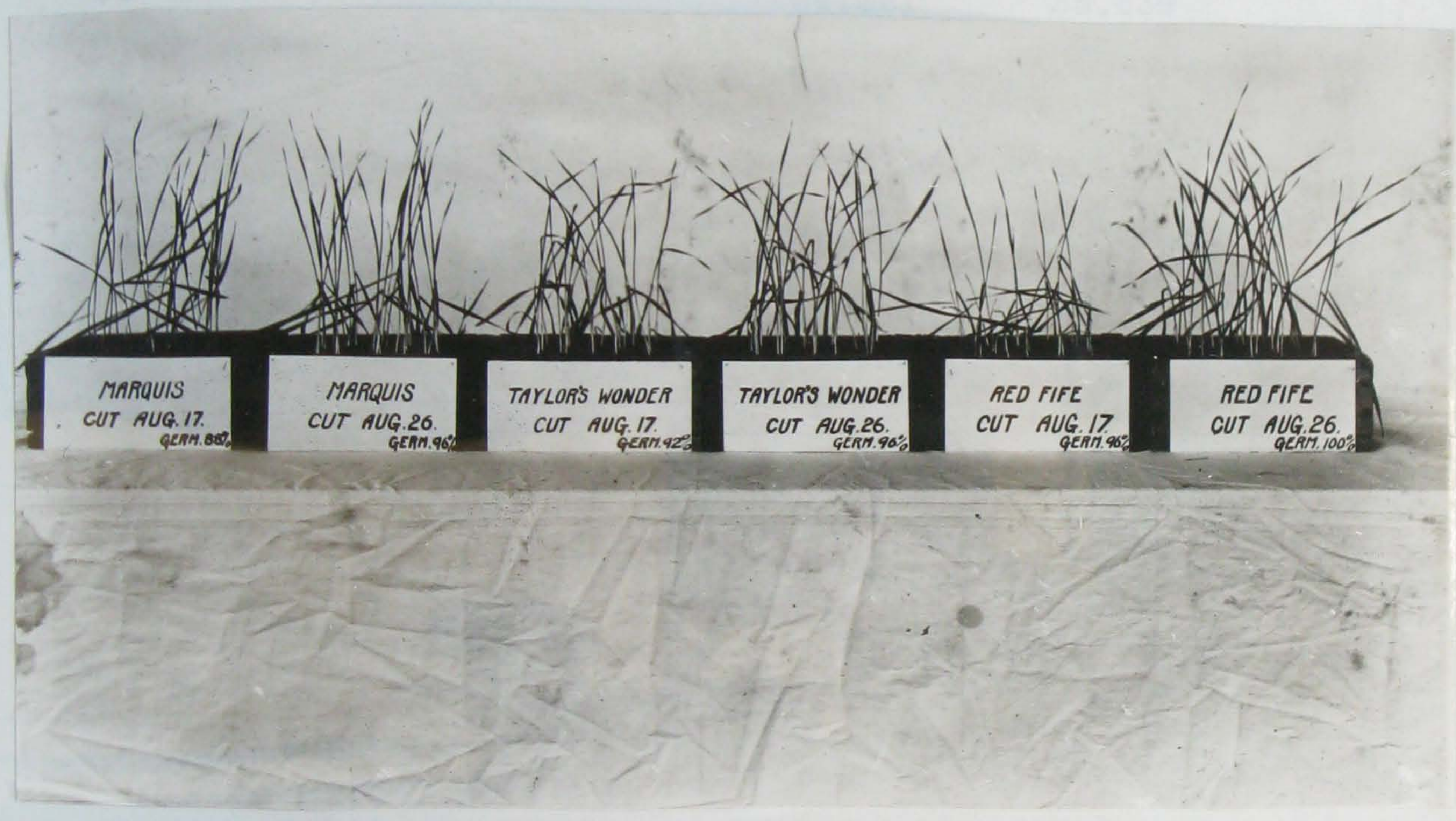
Average of 1st three, middle three and last three dates of pulling.

17,18,19	35.880	35.270
21,22,23	39.856	36.036
24,25,26	42.188	36.866
Gain by leaving till ripe	6.3086 b.p.a. or 17.58%	.766 grams or 4.52%

Average of the first five and last five dates of pulling

17,18,19,20,21	37.865	35.964
23,24,25,26,27	41.183	36.505
Gain by leaving till ripe	3.318 b.p.a or 8.76%	.541 grams of 1.5%

Taylor's Wonder was more severely rusted than either Red Fife or Marquis. Nevertheless a considerable gain in yield resulted from letting it stand besides an increase in the quality of


MARQUIS
CUT AUG. 17.
GERM. 88%
MARQUIS
CUT AUG. 26.
GERM. 96%
TAYLOR'S WONDER
CUT AUG. 17.
GERM. 42%
TAYLOR'S WONDER
CUT AUG. 26.
GERM. 96%
RED FIFE
CUT AUG. 17
GERM. 96%
RED FIFE
CUT AUG. 26.
GERM. 100%

No. 4.

the grain as indicated by the weight of 1000 kernels. Photograph~~s~~ 4 ~~4 and 5~~ again shows a difference in vigor of growth in favor of the later cutting. This is not so noticeable as in the case of Red Fife nor would we expect such to be the case seeing that the weight of 1000 kernels (which determines largely the vigor of growth) in Taylor's Wonder does not show such a difference between first and last cuttings as is the case with Red Fife.

The figures for Marquis are as follows:

Date Pulled	Stage of Developm't	Rust Condition	Total. Wt. of seeds	Wt. of 1000 kernels	Plumpness
Aug. 17	med. dough	med.	39.042	34.428	quite plump
" 18	" "	"	49.200	35.497	" "
" 19	firm "	"	39.116	34.677	" "
" 20	" "	"	34.321	35.639	" "
" 21	" "	"	30.909	35.044	" "
" 22	" "	"	36.947	35.019	" "
" 23	" "	med to bad	32.711	36.144	" "
" 24	hard (ripe)	rather bad	38.585	35.960	" "
" 25	" "	" "	34.126	34.366	" "
" 26	" "	med. to bad	39.665	35.638	" "
" 27	" "	med	32.734	35.388	" "

In the case of Marquis little damage was done to the grain since it was sufficiantly early to escape the damage which the rust caused on later varieties. The sample was practically ready to cut when the samples were first taken so very little difference is noted from letting it stand. The quality of the grain increased slightly (1.26%) between an average of the first five and the last five dates. The yield seems to have decreased slightly but this cannot be attributed to the effect of rust. Photograph No. 5 shows the vigor of growth and % germination of the Aug. 17 cutting compared with that of Aug. 26. A slight increase in the quality of the seed is shown by a slight increase in % germination and in vigor of growth but the difference is not so noticeable as in the other samples.

The weight of 1000kernels is the best guide in determining the gain made by the kernels since there is less chance for experimental error than in the case of the total weight of seeds. It will be noted that a gain in weight of 1000 kernels of each of the varieties tested resulted by leaving the ~~gain~~ grain standing and also that the latest sample (Red Fife) made the greatest gains, Taylor's Wonder next and Marquis the earliest variety, last. A difference is also noted in the vigor of growth as shown by the photographs of the germination tests.

Another experiment conducted under the rust conditions of 1916 illustrates this question ofthe "time of cutting" rusted grain, probably more emphatically than the last one. The material for this was taken from a patch of Marquis wheat which for various reasons was later than the rest of the field and consequently suffered considerably from rust. The main object of the experiment was to determine whether any nourishment passes from the straw into the grain after the crop is cut (in this case under rust conditions). Bearing this in mind 200 plants were cut every two days, care being taken to cut the plants the same distance from the ground in each case. From 100 of these plants the heads were removed at the time of cutting while in the case of the other 100 plants the heads were left on. The material was then bound about with other straw, so as to approximate stook conditions and left in this condition for about three weeks. It was then examined, and the following results were obtained:

Date cut.	Stage of Developm't	Rust condition	Wt. of 100 straws heads remov	Wt.of 100 straws heads retain.	Wt.of100 kernels hds.remov	Wt.of100 kernels hds.retai
Aug.19	soft dough	med		114.4	21.035	23.435
" 21	med. "	"	119.3	123.8	23.740	23.940
" 23	firm "	rather bad	113.7	110.9	25.825	28.265
" 25	" "	" "	116.9	106.4	25.735	27.730
" 27	" "	" "	109.9	117.3	28.520	29.195
" 29	very firm	" "	108.6	111.7	25.635	26.135
" 31	hard dough	" "	116.0	106.5	29.230	30.750
Sept.2	" "	" "	111.4	98.2	28.260	30.525
Average			113.7	110.7	25.997	27.497
Difference			2.34%		5.77%	

A fairly steady increase in the weight of 1000 kernels is noted between the first and last cuttings both in the case where the heads were removed and where they were retained. That considerable nourishment passes from the straw into the grain while in the stook is well illustrated. An average of the 1000 kernel weights shows a 5.77% gain for the kernels where the heads were retained over the case where the heads were removed. This nourishment could only have come from the straw.

An examination of the weights of the corresponding straws, shows on the average a 2.34% decrease in weight of the straw where the heads were retained. Therefore even under these rust conditions a considerable transference of nourishment from the straw to the grain goes on. Of course in a more badly rusted crop the gain would be less and in some cases none at all. This experiment therefore shows both a gain by leaving the crop standing till ripe and also a gain from the straw while in stook. This material escaped frost, so that it certainly paid well to let it ripen rather than cut it green. Of course without rust this same increase, while the crop is maturing would go on. What this experiment shows is that this state of affairs also occurs under rust conditions where the crop is not very badly damaged and that therefore under such conditions it does pay to let the grain ripen in the field rather than cut it in a green state.

Averages of the first four, and the last four dates. of cutting for the 1000 kernel weights are as follows:

Dates.	Wt. of 1000 kernels heads removed	Wt. of 1000 kernels heads retained	Gain from the straw while in stook
Aug.19,21,23,25	24.084	25.842	7.29%
Aug.27,29,31,Sept.2	27.911	29.151	4.44%
Gain by leaving the grain standing until ripe	15.89%	12.80%	

It will be noted from these figures that a greater gain from the straw while in the stook takes place in the earlier cuttings, than in the later cuttings, but the later cuttings have the additional gain from the straw while in the field, so that, the total gain in the case of the later cuttings is considerably greater than the total gain, where the crop is cut green.

Photograph 5 shows a considerable difference in the vigor of growth and % germination between the first and last cutting. The photograph also shows how the nourishment acquired from the straw while in the stook (heads retained) produced a greater vigor of growth than in the case where this nourishment was not obtainable (heads removed). This is illustrated by both first and last cuttings. The vitality or germinability however does not seem to be impaired by removing the heads (same % germination in each case). The difference in vigor of growth seems therefore to be due to the extra nourishment gotten from the straw.

A chemical analysis of the grains of several of the dates of cutting show an increase of protein where the heads were retained

No.5

over the case where the heads were removed at the time of cutting, also on the average, the later cuttings show a higher content protein, as would be expected.

Chemical Analysis of Grain

				Total Protein
Marquis	Aug. 21	- Heads	removed	6.204
"	" 21	"	retained	6.610
"	" 25	"	removed	7.811) #
#	" 25	"	retained	9.353)
"	" 29	"	removed	7.427
"	" 29	"	retained	10.54
"	Sept 2	"	removed	9.007
"	" 2	"	retained	9.152

The order of these figures was reversed in the report made by the chemical department. It looks however as if a mistake in labelling must have been made since the other dates of cutting all show a larger per. cent. protein for the "heads retained" sample.

Should Rusted Straw be Used for Feed?

We have seen that rust does not entirely cut off the passage of nourishment from the straw to the grain. It does however to considerable extent as is evidenced by the shrivelled condition of the grain from rusted crops. For this reason we would expect the straw from a rusted crop to be richer in food material than that of a rust-free crop. The following chemical analysis submitted by the Dominion Chemist, Dr. F.T. Shutt shows this to be true.

	Moisture	Crude Protein	Crude Fat	Carbo-hydrates	Fibre	Ash
Straw from rust-free wheat	7.92	2.44	1.65	39.00	39.95	9.04
Straw from rusted wheat	7.92	7.69	1.97	38.00	36.78	7.20

In this case it will be seen that the rusted straw contains over twice as much crude protein as the rust free sample, and also more fat, but slightly less carbohydrates and considerably less fibre and ash. Protein is an essential part of a ration and seems to be the hardest to obtain. Rusted straw is much superior in this constituent and therefore much more valuable than rust free straw as a stock food.

The main reason however why farmers are cautious about feeding rusted straw is the fear of poisoning their animals. Such fear however is unfounded. Rusted straw has been fed this season and after other rusted seasons with good results. A few instances are recorded where farmers claim their stock have died as a result of eating rusted straw. These are isolated cases however and if traced to the real cause one would no doubt find the deaths were due to poisonous weeds or some cryptogamic poisoning other than rust. Conditions which favor rust also favor other cryptogams some of which are known to be poisonous. If rusts were poisonous there would be a more general outbreak of poisoning in rusted areas, where rusted straw is being fed.

Where straw is very badly rusted, it is of course likely to be of very little feeding value, simply because a large part of the nutritive material has been consumed by the rust parasite. In such cases the straw becomes actually rotten and looks somewhat similar to straw that is decayed from any other case. It may be foolish to feed such straw, but it is not known, that it will cause any injury to the animals, to which it is fed.

When cutting badly rusted grain the spores fly about in the air, forming a fine dust which sometimes irritates the nostrils and throats of men working in the field. This injury is purely mechanical however such as would be caused by any dust, and cannot be attributed to any poisonous effect of the rust spores.

The Wind as a Factor in Spreading Rust Infections

Professor Bolley of the North Dakota Experiment Station has shown that it is possible for the three chief species of grain rust to winter in North Dakota and thus produce the disease the following Spring. He considers however that the chief source of rust-spores lies to the southward where the cereal crops and native grasses mature earlier and in time for the spores to blow northward and westward. Thus the southeast winds are the chief carriers of rust spores. The same applies to this part of the world. The general outbreak of rust here this year could have come from no other source than wind blown spores from southern fields. The disease is carried from field to field by the wind, each newly infected field serving as a centre for further infection. Wherever the spores germinate best the infection will be worst. Thus local showers and heavy dews may cause a greater amount of rust in some parts than in others, so that great ~~areas~~ areas may miss destructive infection because of special conditions prevailing there.

To show that spores are daily carried in the air Professor Bolley carried out several tests. Ordinary soup dishes, seven inches across the top were exposed, half-filled with distilled water upon posts for fixed periods of time. After sedimentation in a centrifuge machine observations upon the spore content were made. Some of the results are as follows:

July 21st	Plate exposed 45 minutes. Found 2 Puccinia Rubigo vera (Brown rust) in 6 mounts of the sediment.
July 24th	Plate exposed 30 minutes. Found in 6 mounts of sediment, 6 uredospores of Puccinia Rubigovera, 4 uredospores of P. Graminis, and one teleutospore.
Jly 26th	Plate exposed 30 minutes after a heavy rain of previous night. In 6 mounts, 8 uredospores of P. Graminis and 4 of Puccinia Rubigovera.

There results would seem to show that uredospores are widely distributed by wind currents. Thus an infected section may, by means of the wind be the source of infecting a later maturing crop in a distant section of the country. Locally windy weather at the time the crop is most susceptible is beneficial since it tends to keep the plants dry and thus prevents spores remaining on them and germinating. Hot dry winds after outbreak of pustules is produced however is a great source of spreading the disease.

<u>How Does Rust Winter in this Country?</u>

Nature has made provision in the case of P. graminis and other Uredinales to tide them over adverse conditions such as winter. This provision is the thick-walled teleutospore which has been previously mentioned. These will stand extremes of heat and cold. Evidence of this is shown by the fact that Professor Buller of Manitoba Agricultural College has been successful in germinating them after having survived a Manitoba winter (where it is not uncommon for the temperature to reach 50° below zero).

Even if teleutospores do survive our winters readily they could not produce any general infection in the Spring since the only hosts which the spores, that they produce on germinating can attack are the Barberries. These shrubs are certainly not plentiful enough on our prairies to spread the disease to any great extent.

There are several other possibilities by which P. graminis may survive the winter (1) by the wintering of the uredospores (2) by a perennial mycelium (3) by Eriksson's mycoplasm. The third possibility has been discussed in another connection. It is merely a theory and one which other investigators have very little faith in. For this reason it will not be considered further.

The second possibility is subject to a considerable diversity of opinion. DeBary and others have searched in vain for mycelium in the growing wheat plants before infection becomes visible but Pritchard (1911) (previously mentioned) proved that the mycelium from infected wheat kernels passes into the tissues of the young seedling where it grows rapidly. As yet however this has not been shown to be the cause of epidemics of rust. Some rusts are known to have a perennial mycelium, e.g. Phagmidium. In this case the mycelium remains in the tissues of the host plant all winter and continues to grow again in the spring. This may be the case with wheat rusts. Rust filaments may persist in green leaves and other green parts of wheat (winter wheat) and other grass host plants (perennials) which may chance to live through the winter. Professor Bolley considers that such is thoroughly proved for the Brown Rust of wheat and quite possibly for Puccinia Coronata and Puccinia Graminis

The third possibility seems to be the mostly likely method by which P. Graminis and other cereal rusts winter in the absence of their aecidial hosts. Climate is the limiting factor, If uredospores are viable in the Spring they can directly infect the wheat crop, whereas teleutospores must first infect their aecidial hosts. McAlpine and Cobb find viable uredospores all the year round in Australia and Lagerheim says the same for Ecuador. In northern climates such as Sweden and North Germany it has been shown that the uredospores of P. Graminis frequently lose all capacity for germination. On the other hand Professor Bolley has been able to germinate uredospores of both the Brown rust and Black rust of wheat after being frozen in snow and ice all winter, as far north as Fargo, North Dakota. Moreover these uredospores frequently showed a remarkably high percentage germination as shown by the following observations made at Fargo during the season of 1905 --

Feb.17th Found the red spores of Puccinia Graminis on green leaves of Agropyron repens (quack grass) frozen in solid ice. 85 - 95% of these germinated on first trial.

Feb. 22nd Found uredospores of Puccinia rubigo-vera on green leaves of Agropyron repens (quack grass) frozen in snow and frozen in ice). These spores gave a high percentage germination.

The writer collected some rusted wheat from plots covered with snow (10 inches deep) at Saskatoon on March 12, 1917.

Uredospores of Puccinia graminis were obtained from this material and placed in a hanging drop of dextrose solution. A large percentage germinated in less than twenty-four hours showing that even this far north uredospores can survive the winter. The same may be said for the conidia of Alternaria since spores of this fungus from the same source as the uredospores of P. graminis acted similarly. Whether after the freezings and thawings and drying of spring these spores will have sufficient vitality left to infect wheat plants is a matter yet to be determined.

If the uredoppores readily survive our winter and produce the disease again in the spring, or if the mycelium of the disease lives over within the tissues of perennial grasses, the burning of straw and wild grasses if generally conducted, should largely eliminate these sources of infection. If only a few took such precautions it would do little or no good, since fields so treated would readily become infected from neighboring fields that were unburned.

If we intend to keep down rust it is evident that we must take all measures possible to combat it and if the burning of stubble and wild grasses can be shown to lessen its ravages it certainly should be generally practiced after an epidemic of rust.

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